Development Derailed: Uncertain Property Rights and Asset-Specific Investment

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Abstract: Theory predicts that property rights coevolve with value and investment, making empirical identification of causal effects difficult. We identify how uncertain property rights – exogenously generated by railroad land grants – delayed and deterred investment and economic development on the Western frontier. We explore the impact of the Northern Pacific's land grant in Montana because it encompassed nearly 50 percent of the state while the delayed construction of the NP and a large shift in political sentiment in the interim created significant uncertainty to title for the land grant for at least 15 years. We examine how this uncertainty to title impacted irrigation investment because it exhibits high asset specificity, was central to economic development on the frontier, and has a readily observable date of initial investment thanks to western water law. Using granular spatial data on land patents and water rights, we exploit the random variation of the checkerboarded land grant in a difference-in-differences as well as the arbitrary 100-mile width of the grant in a spatial discontinuity to overcome the empirical challenge that property rights and investment are often endogenously determined. We find that the uncertainty delayed (4.2 years) and deterred (28 percent lower) irrigation development in Montana. We estimate this reduced total farm value by up to 27 percent in Montana, which in annualized terms, accounted for nearly 6 percent of Montana's total income in 1930.

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> *"Large numbers of settlers are occupying such [railroad grant] lands, and it is important to them to know whether they can receive their titles from the United States, or whether they will be required to purchase from the railroad companies. The prevailing uncertainty necessarily retards improvements and impairs values."*
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> - N.C. McFarland, General Land Office Commissioner, *Annual Report of the Commissioner of the GLO*, 1882, pg. 11.

Introduction

Property rights world-wide remain weak or insecure due to a lack of formal title and inefficient or corrupt judicial and administrative processes. A 2019 report found the global average property right index for countries is just 53 (out of 100) (Miller et al. 2019). Furthermore, poorer groups of people typically have lower levels of security within countries (Deininger 2003). As a result, many advocate for increasing tenure security in order to spur economic growth (e.g. de Soto 2000). The premise has well-developed theoretical underpinnings – assurance of investment returns, collateral for loans, and the ability to sell assets all can improve economic outcomes (Besley 1995) – but empirical estimation remains challenging and has yielded mixed results (see Lawry et al. 2014 for a review). At issue is that causality can run both ways as property rights coevolve with value and investment (Demsetz 1967; Alchian & Demsetz 1973). First, otherwise more valuable assets justify the cost of obtaining formal title (Alston et al. 1996), and second, fixed investments can strengthen informal claims (Brasselle et al. 2002; Sjaastad & Bromley 1997).[1] Relatedly, given the frequently endogenous nature of property rights' emergence through changes in relative prices, undertaking to better specify and enforce rights in a centralized fashion is not always appropriate as it can entail costs that exceed the benefits of additional rights definition (Arruñada 2012).

This endogenous relationship between property rights and the underlying value of the asset has been no less important historically. Scholars considering the development of the U.S. West throughout the 19th Century have consistently identified the importance of property rights to natural resource development (e.g. Anderson & Hill 1975, Libecap 2007, Allen 2019). From mineral deposits, to ranching, to agriculture and forestry, the natural resource wealth of the U.S. West proved to be a major input to the U.S. economy (David & Wright 1995, Wright & Czelusta 2004). Settlers sought secure land, water, and resource rights so that they could be sufficiently

[1] From a philosophical standpoint, this aligns with the Lockean idea that property rights are derived from mixing your labor with the natural asset as Locke laid out in his 1690 Treatise on Government (Locke 1980).

confident they would appropriate the returns of their investments in resource development – often characterized by a significant degree of asset specificity. For instance, absent the development and adoption of the more defined prior appropriation doctrine for water rights, irrigators would have made more limited investment in diversions and the agricultural sector would have been hampered (Leonard & Libecap 2019).

But absent the ability to get the fruits of agriculture and other industries to market and laborers to work in both these pursuits, the level of development would also have been lower, making the early transcontinental railroads important to the frontier (e.g. Fogel 1962, Donaldson & Hornbeck 2016). Construction of railroads from 1850-1870 was heavily subsidized through extensive land grants which provided the companies over 150 million acres (Atack & Passel 1994, pp. 436). Despite the market access gains garnered, the wisdom and need for the grants have been generally debated (Ellis et al. 1946, Mercer 1982, Allen 2019) and shifts in the political economy led to significant forfeitures of these grants (Ellis et al. 1946).

Our efforts here seize on the circumstances of the Northern Pacific Railroad (NP) to empirically identify how important secure land ownership, or at least a clear path to title, is for undergoing economic investment. For many decades, though most acutely from 1879 to 1894, it was unclear whether the NP would retain title to some 40 million acres that the government had granted them to subsidize construction, leaving settlers in legal (and political) limbo. With nearly 50 percent of its area falling within the limits of the land grant, Montana was most extensively impacted. We examine how this uncertainty to title impacted investment, specifically in irrigation, because irrigation exhibits high asset specificity, was central to economic development on the frontier, and has a readily observable date of investment thanks to western water law. Our empirical strategy addresses the dual causality surrounding economic development and clarity of property rights. We are not the first to address this (e.g. Besley 1995; Alston et al. 1999; Brasselle et al. 2002; Hornbeck 2010), but our historical context and an associated set of empirical techniques – difference-in-differences and spatial regression discontinuity – allow us to identify a causal effect of property rights on asset-specific investment and economic development on a large scale. We find that uncertainty of ownership deterred and delayed irrigation investment; with insecure title, lands were 28 percent less likely to be brought under irrigation than similar areas and, if irrigated, done so 4.2 years later. We calculate this reduced agriculture land values in Montana between 7 and 26 percent, depending on the counterfactual assumptions.

I. Property, Irrigation, and Railroads

I.A. Property rights and natural resources

Better specified property rights tend to emerge as relative scarcity increases; transforming the situation from one of de facto open access to one where the returns of increasingly well-specified property rights outweigh the costs of such rights' creation and enforcement (Demsetz 1967). Investors will strengthen rights – whether by bearing costs to obtain legal title, expending resources to self-protect, or even investing in an asset directly to strengthen a de facto claim – when the benefits of doing so outweigh the costs. But the benefits themselves are often the product of greater tenure security: investors are more willing to invest in ways that enhance economic productivity, a point which has been well-developed theoretically while empirical evidence remains mixed (e.g. Besley 1995; Brasselle et al. 2002; Johnson et al. 2002; Lanjouw & Levy 2002; Goldstein & Udry 2008; Galiani & Schargrodsky 2010; Fenske 2011; Liscow 2013; Newman et al. 2015).

Studies of arrangements governing property in the frontier west have demonstrated this trend broadly occurred for numerous resources (e.g. Libecap 1989; Anderson & Hill 2004). Because the vast majority of land in the West was owned by the federal government, the process of western economic development involved vast swaths of public land being converted into private property rights to minerals, land, and water (Hibbard 1924; Swenson & Gates 1968). This meant that in order to secure one's right to benefit from costly improvements, the public laws governing natural resource and land disposition, including railroad land grants, were of central importance to settlers who intended to invest in durable, asset-specific projects like irrigation.

Identifying the productivity effects of property rights remains a challenge because they are more likely to emerge where resources are of better quality (Besley 1995, Alston et al. 1996, Kaffine 2009, Galiani & Schargrodsky 2010). Hornbeck (2010) overcomes this issue by drawing an exogenous shift in the costs of protecting property rights and Leonard & Parker (2019) consider the impact of property rights determined prior to the discovery of valuable subsurface resources.[2] We are able to isolate a causal effect of insecure property rights because: (1) the NP

[2] They consider spatial scale and anti-commons issues, not security of title.

land grant provides random variation in secure ownership across similarly endowed units of land; and (2), in contrast to informal systems of tenure where fixed investments, like irrigation, can be made to strengthen claims, the incentive to do so is not present in contexts, like ours, where the determination of *formal* title will carry the day (Sjaastad and Bromley 1997).[3]

I.B. Irrigation

Owing to the aridity, water greatly determines the ability to produce cattle, refine minerals, and raise crops in the West. Water rights adjusted quickly to the relative scarcity that predominated in arid western states, an adjustment that resulted in the doctrine of prior appropriation. Prior appropriation gave certainty to irrigation developers that their investments in ditch construction would yield an expected amount of water as a function of when they had appropriated water from a particular watercourse (Leonard & Libecap 2019). Importantly, this system also created strong incentives for water users on the frontier to formalize their appropriation date as soon as feasible, a fact our identification strategy exploits.[4]

While attention has been given to the rationale and impact of secure water rights in the West, little if any attention has been paid to the need of accompanying land rights to induce investment. Certainty to land title is an input to costly irrigation development because irrigation ditches are highly idiosyncratic investments given that the construction costs are sunk, location is important, and the ditch cannot be used for anything else (Williamson 1979, Bretsen & Hill 2007). Thus, spurring investment in irrigation along an arid frontier required a certain level of certainty to the land independent of the water rights. In the US context, this element may have been overlooked due to the prevailing strength of land title subsequent to the mineral rushes arising from the public land survey and various land laws. However, in certain contexts – including the expansive NP land grant – uncertainty in ownership still impacted economic decisions and subsequent outcomes.

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[3] This is not to diminish the role of the initial informal and local systems that arose on the western frontier and helped to shape formal mineral rights and water rights (e.g. Umbeck 1977, Libecap 1978, Clay & Wright 2005, Alston, E. 2019) and the informal grazing claims (e.g. Alston, Harris, and Mueller 2012, Libecap 1981). Rather it is to note that formal ownership ultimately came to dominate in this context and the NP land grant issue was of a significant scale that all three branches of the national government were involved, giving salience to the formal determination in this case.

[4] The appropriation date was the date that a given water user had put water from a natural stream to a "beneficial use". Doing so ensured the prior appropriator's rights against all other more junior appropriators.

In addition, the size of individual farms on the frontier was typically smaller than the size of organizations needed to fund and operate irrigation ditch projects, requiring significant levels of coordinated investment (Teele 1904, Coman 1911, Bretsen and Hill 2007, Ostrom 2011, Libecap 2011, Hanemann 2014, Leonard & Libecap 2019). Given the need for certainty of land and water rights to induce agricultural output, this suggests that the larger the investment a particular output required, the more sensitive to certainty in land titles a given investor or group of investors would be.[5] Asset-specific investments involve sunk costs that are salient before the investment is made – this makes such investments especially sensitive to uncertainty of downstream rents that result from the asset-specific components of the investment. In other words, supply of irrigation projects (being asset-specific, large-scale and costly) was likely more elastic to property rights defects than individual economic activities along the frontier.

I.C. Railroads and US Economic Development

The contributions of railroads to the U.S. economy is a well-trodden area of economic history. Perhaps the best known historical analysis of the economic impacts of railroads in the U.S. West is the canonical work of Robert Fogel (1962, 1966, 1979), which found a significant benefit to the railroads, albeit significantly less than the transformational effect that had been argued by other historians up that point (Fogel 1962).[6] Subsequent economic historians picked up where Fogel left off and continued to refine the general understanding of the contributions of the railroads to economic development and the wisdom and impact of the land grants themselves. However, many of these studies rely on specific assumptions surrounding interest rates, risk, and other economic variables. Unsurprisingly, then, these existing studies paint a mixed picture of the land grants, not only in terms of economic development itself, but also in terms of objectives beyond development that may have induced the policies.[7] Furthermore, other scholars have

[5] Asset specificity interacts in important ways with economic incentives and therefore influences contractual and associational forms (Williamson 1983), as well as investment choices directly (Coles & Hesterly 1998). Empirical work has also shown that asset specific investments are sensitive to tenure security in a number of developing world contexts (Bruce & Migot-Adholia 1993). Furthermore, other sources of uncertainty have unsurprisingly been shown to influence investment levels (Bulan et al. 2009) including irrigation investment in particular (McClintock 2009).

[6] Fogel's exact question remains one that motivates economic historians. Unpublished works from 2013 (Swisher) and 2014 (Pereira et al.) put the contribution of railroads to economic development as significantly higher than the estimate reached by Fogel.

[7] A number of studies conclude that the grants were dubious public policy, either in their entirety (Wahlgren Summers 1993; Atack & Passel 1994) or with respect to specific railroads (Mercer 1982). Other assumptions regarding key economic variables or inclusion of additional measures instead yield conclusions that some or all of the railroad land grants were on net beneficial (Mercer 1982; Emery & McKenzie 1996; Heckelman & Wallis 1997).

argued that the checkerboarded allocation of the land grants had persistent effects on resource development, often in terms of actual ownership.[8] Recent scholarship has also considered the net benefits of the railroads, coming to more broadly net beneficial conclusions.[9] Instead of considering the benefits of the railroad land grant projects writ large, which varied considerably in their terms and the presence of government financing, we instead focus here on a specific cost to one of the largest railroad land grants.

We build on all these literatures surrounding property rights, irrigation, and the effect of the railroad land grants, by examining a huge swath of checkerboarded land in Montana subject to titling uncertainty for well over a decade. We argue this uncertainty negatively influenced irrigation development at levels measurable well into the 20th Century. To our knowledge, our work is the first to explore how the land grants influenced the development of water. And while we build on the empirical methodologies exploiting the checkerboard land grants (e.g. Lewis 2019; Edwards et al. 2019), our setting identifies how uncertainty of ownership, rather than eventual ownership patterns, impacts investment in resource development. Because a large portion of irrigation development occurred more contemporaneously with the railroads, in contrast to later oil and gas development, we capture how the uncertainty affected investment at the time. And while our disaggregated data (40-acre units) permits careful identification of the micro-level causal impact of uncertain property rights on asset-specific investment, the natural experiment that we draw upon to do so impacted such a large portion of Montana (among other states) that we are also able to document significant negative impacts on Montana's economy at large. Furthermore, our findings qualify the gains of the land grants that previous scholars have argued accompanied the railroads themselves, providing more context for the large public hand out.

[8] For instance, in the timbered Pacific Northwest, railroad grants held large swaths and were harvested differentially from the surrounding federal lands (Appleman 1939, Cotroneo 1976). The impacts of ownership (private, state, or federal) on oil and gas development in Wyoming has been assessed on the checkerboard, with land originally granted to the rail developing more quickly (Edwards et al. 2019). Eric Lewis (2019) also looks at state ownership in Wyoming but finds that policies on state lands spatially spillover onto nearby non-state land.

[9] David Donaldson and Richard Hornbeck (2016) returned to Fogel's question with sophisticated GIS analysis and measures of market access provided by rail networks to better understand the aggregate impact of railroad construction capitalized agricultural land values, concluding that based on this incomplete measure alone, the addition of railroads added 3.22% to GNP by 1890. Douglas Allen has also argued the land grants, along with the Homestead Act, despite appearing dissipative due to rushing settlement, in fact were part of a larger concerted effort by the federal government to secure legal claim to its relatively new territory that may have otherwise been ultimately lost or maintained only at great military expense (Allen 1991, 2019).

II. Railroads and Uncertainty in Montana

II.A Northern Pacific Land Grants

Between 1850 and 1871, the government sought to encourage private investment in railroads through land grants, authorizing the transfer of 158 million acres to private railroad companies (Atack & Passel 1994, pp. 436). In general, these grants followed a clear policy from 1862 onwards. Once a railroad had filed a map of its general route with the General Land Office (GLO), the railroad company would begin construction within the timelines specified in the particular act authorizing their incorporation. As a given railroad company completed the specified sections of rail (ranging from 1 to 40 miles), the GLO would issue patents for the odd-numbered sections of public lands[10] lying on either side of the railroad right-of-way (Decker 1960 at 83). The result was a "checkerboard" of ownership with the Federal Government retaining ownership of the remaining sections (Greever 1951 at 83-84). Railroad land grants also included "indemnity lands," which was another band of land beyond the primary grant from which a railroad could select land to substitute for any land within their grant found to be deficient, often due to prior settlement.[11] The question of whether settlement could legally occur on lands designated to the railroads upon completion of sections also became a major controversy, for the GLO withdrew land grant sections from settlement upon the filing of the rails definite location (Julian 1883, at 251-252; Powers 1889), although the extent to which they adhered to this in practice varied considerably depending on the administration.

We draw upon the NP case, because, in the words of one historian, "[i]n the size of its land grant, but also in its violations, controversies, investigations, and lawsuits, the Northern Pacific had no peers." (Daffran 1998). Just months after Montana became a territory, the NP was incorporated (Act of July 2, 1864, ch. 217, 13 Stat. 365) and was granted a primary area of 20 sections (12,800 acres) for each mile of railroad constructed in a given state, and 40 sections

[10] The Land Ordinance of 1785 set out the Public Land Survey System in which land was to be demarcated ahead of settlement in a rectangular grid. From principal meridians, townships (6 by 6 miles) were established and subsequently divided into 36 numbered sections, each 640 acres. These sections could be further subdivided into halves (320 acres), quarters (160 acres) and even quarter-quarters (40 acres). Our identification strategy relies on using a many of these units as mapped to GIS data in the state of Montana. See Appendix B, Figure B1 for an illustration. For more detail and analysis of the benefits and costs of the PLSS system, see Libecap & Lueck 2011.

[11] Cash sales and homesteads account for 52 percent of public land dispositions while railroad grants account for another 12 percent (Daffran 1998), although in Montana this latter percentage was much larger, due to the percentage of the state that was covered by the Northern Pacific land grant.

(25,600 acres) for each mile of railroad constructed in a given territory.[12] In total, this meant some 42 million acres for the railroad. The amount in Montana totaled 14,739,697 acres (15.8 % of total state acreage[13]), which stands as the largest land grant to the railroads of any state/territory in the country (Swenson & Gates 1968, 385), and nearly ten percent of the total lands granted to all railroads during the 1850-1871 land grant period. When the indemnity band was included, the 15 million checkerboarded acres became interspersed with 26 million non-railroad grant acres fanning out 50 miles in both directions from the railroad, totaling nearly 50 percent of Montana, which is shown in Figure 1. The grant set a time constraint of July 1, 1879 for the completion. The NP did not begin construction until 1870[14], beginning at Duluth, MN and Kalama, WA (Mercer 1982 at 53).

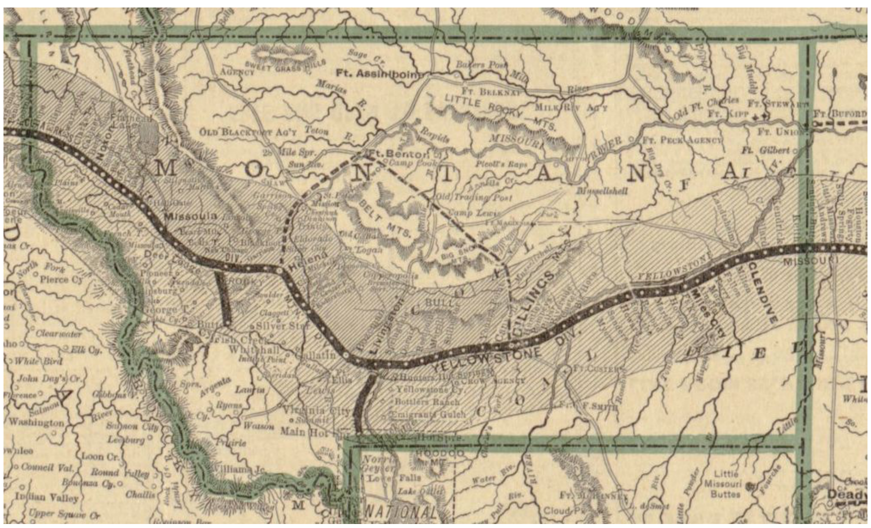


Figure 1: Northern Pacific Land Grant Map in Montana, 1883. Source: https://www.loc.gov/item/98688749/

The construction of the NP proceeded eastward in the Washington Territory and westward out of Minneapolis into the North Dakota Territory until September 18th, 1873, when the company selling bonds to finance the railroad construction went bankrupt. The NP subsequently defaulted on bond interest payments in 1874, and went into receivership in 1875. As the grant land was not patented to the NP due to the railroad's failure to complete

[12] See Appendix Table B1 for a summary of the relevant NP timeline.

[13] Total area from "Montana Agricultural Facts 2018." National Agricultural Statistics Service, published April 2019. https://www.nass.usda.gov/Statistics_by_State/Montana/Publications/Special_Interest_Reports/agfacts.pdf

[14] This same year, an additional indemnity belt of ten miles was added to the original ten-mile strip on either side of the primary land grants, with the condition that it could be selected only to make up for lacking primary grant lands in a given state or territory itself (Act of May 31, 1870, 16 Stat. 378, 378–79 (1870)). This brought the total band of land surrounding each side of the railroad right of way to sixty miles, though the final indemnity band did not induce equal amounts of uncertainty.

construction of its route, this land was not sold to pay off the company's debts.[15] Under a new railroad president from May 24th, 1879 onwards, the NP proceeded over the next four years to complete construction on its route as originally specified (Mercer 1982 at 53-54).[16] In the same time period, the NP heavily lobbied members of Congress to grant the line a time extension, due to the construction period falling outside the original time limits. Fearful the NP would not extend into Montana, the U.S. Survey General, Roswell H. Mason, reported "I believe that the great majority of our people agree with me in the wish and hope that congress will extend the time for its completion, thus securing to it the land grant, and to us and the country generally far greater benefits." (GLO 1880, pg. 583). The effort was ultimately unsuccessful, and so the NP had to rely on the original grant, despite the movement toward land grant forfeiture at the time (Clinch 1965). The main line was completed August 22nd, 1883 (Taylor 2010), over four years past the statutory deadline.

Overall, the amount of land granted to the railroads to support rapid development became a well-documented political controversy, especially as railroads missed their construction timelines and contempt for the Railroad Barons grew. While the Credit Mobilier scandal – which by one account lined the Union Pacific stockholders' pockets through defrauding the government of $20 million (Wahlgren Summers 1993) – was the most salient outcome involving corruption in railroad development, the perception of abuses on the part of the railroads was widespread[17] (Roberts 2011 at 126-128). Congress responded by actively considering forfeiture of specific land grants from 1867-1894, though 1877-1890 was the most active in terms of actual forfeitures (Ellis 1946). Over a four-year period from 1884 to 1887, 6 statutes were passed forfeiting over 28 million acres from 10 railroads (Ellis 1946, Daffran 1998). The General Forfeiture Act of 1890 largely put the debate to rest, forfeiting 5.5 million acres from railroad lines still incomplete (Ellis 1946).

[15] Despite being reorganized in 1875, the company was largely inactive until late 1879, with exception of construction of a small extension in Washington Territory in 1876-1877 to facilitate access to coal fields.
[16] Although the NP ultimately ended up paying another railroad to use a small section of their line in Washington Territory (and subsequently, the state), this does not become an issue for awarding land grants to railroads until the litigation of indemnity land claims in the early 1900s that lasted until 1941.
[17] These perceived abuses were in many cases directly related to the land grants themselves, including the use of dummy entrymen to evade public sale provisions of land grants, delays in surveying and patenting the grants to evade property taxes, speculating with land grant lands, and exchanging the grant lands for other more desirable government lands. (Julian 1883).

While it ultimately does not come to pass, our identification strategy relies on the looming and credible threat of forfeiture of NP lands in Montana throughout this period and the underlying uncertainty of title induced for large portions of the territory. As noted above, the NP was seriously concerned about forfeiture of its land grants, lobbying Congress to extend its statutory timelines to no avail (Schwinden 1950). Efforts to force the forfeiture of the NP grant were relentless and repeated but a difference in opinion between the House, which passed four NP forfeiture bills throughout the 1880s, and the Senate, which voted them all down, seemed to preserve the status quo of uncertainty[18] (Fairweather 1919; Ellis 1946). In response to the controversy[19], the GLO simply withdrew granting patents to the NP in 1885, and only issued its first patent in Montana in 1894. Because of the congressional and administrative uncertainty, homesteading within the land grant faced considerable risk. Lewis Haney (1910) described the potential folly: a settler takes up land within the grant, making improvements with the rail's consent and assurances of the privilege to purchase first, only to find in the final location adjustment or forfeiture, the land is restored to the public domain and the settler upon it finds they have no title (p. 30).

Furthermore, the GLO commissioner noted that railroad companies aggressively antagonized claimants to "compel settlers to purchase railroad waivers or relinquishments of lands to which the companies had not and might never have any color of legal right; to appropriate the products of coal and other valuable lands" (GLO 1885, pg. 29), only to turn around and claim deficiencies and seek replacement land from the indemnity band (GLO 1885, pg. 28). While the NP may have sought any valuable improvements, as the preceding quote suggests, they were prone to claiming primary and indemnity lands where minerals had been

[18] The House favored the forfeiture of all lands adjoining the 1,739 miles of uncompleted rail (over 1/5 of the total) as of the original deadline while the Senate favored forfeiture of only the lands adjacent to what remained uncompleted at the time of a given forfeiture bill under consideration (Ellis 1946). Montana's portion of the land grant, with most of its rail completed from 1881-1883, hung in the balance. The House passed similar NP forfeiture bills in 1882, 1884, 1886, and 1888 (Ellis 1946). The 1888 act passed the house 179-8 and was explained to some Montanans in the Dillon Tribune to extend to land "sold by the company prior to 1888 to bona fide purchasers", but that "all settlers upon forfeited lands are authorized to acquire title to not exceeding [sic] 160 acres under the homestead act." (The Dillon Tribune, September 28, 1888).

[19] One well-publicized case involved President Cleveland publicly rebuking the office for siding with the NP in a dispute over an indemnity claim that had been developed following the passage of the NP land grant: "After a lapse of seventeen years this large body of the public domain is still held in reserve to the exclusion of settlers, for the convenience of a corporate beneficiary of the government and awaiting its selection, though it is entirely certain that much of this reserved land can never be honestly claimed by said corporation. Such a condition of the public lands should no longer continue." (Powers 1889)

discovered, arguing that its statutory grant and the GLO's selection withdrawal predated valuable mineral claims that had subsequently been discovered and developed, a practice that led to significant public and political controversy within the state of Montana[20] (Clinch 1965). The level of public awareness in Montana of the NP opportunistically claiming valuable developed mineral lands, many of which were publicly argued to have been officially designated as agricultural, in a context of such uncertainty surrounding who would get the patents to those lands, likely affected individuals' willingness to try to develop those lands for irrigation purposes.

Two final points of history bear examination in light of our empirical approach. First, although the NP was the first railroad to cross Montana, it was soon followed by another major railroad project, the Great Northern, which crossed a more northern portion of the state of Montana (see Appendix Figure B2 for a map). The Great Northern had reached Montana by 1887, and construction on the line all the way to the Pacific finished in 1893 (Hidy 2004). Unlike the NP, however, the Great Northern did not receive any land grants to subsidize its construction in the state of Montana. This creates an ideal comparative context in which to explore land and irrigation development alongside the Great Northern's route in Montana. This makes the area surrounding the Great Northern a critical control and explicitly useful for placebo tests by which to consider the rate of land development that a railroad could create.[21] Second, we also draw on the Kansas Pacific land grant in Colorado (see Appendix Figure B3 for a map). Incorporated in 1866, it was constructed in just 4 years and received its 20 sections per mile with little doubt (see Appendix B, Tables B2 for a timeline). We draw on this land grant and Colorado to distinguish the impact of land grants and checkerboarding on irrigation more generally as compared to the *uncertainty* induced by the NP land grant.

[20] Local headlines like, "They Want the Earth; An Attorney of the NP says the Anaconda Mine is Theirs." (The River Press, May 27, 1891) highlight the NP's willingness to assert claim to lands along with fixed asset-specific investments. Indeed, the NP argued in the Supreme Court case that put an end to the practice in 1894 that land within the grants originally designated by the GLO as agricultural should belong to the railroad, regardless of whether or not valuable minerals were later discovered by third parties upon them (Barden v. North Pacific 1894 at 292-93). The issue reached national salience in the New York Times article (January 12, 1892), "A Montana Question. Trouble growing out of the Northern Pacific's land grant." Citing the NP's willingness to contest patents granted to members of the public within its grant, the article states, "[t]he result was to unsettle titles and tie up large and valuable properties."

[21] Earlier generations of economic historians identified this comparative possibility (Cochran 1950; Rae 1952), with one noting that the Great Northern's "construction invites comparison...with the well-endowed Northern Pacific." (Rae 1952 at 140).

II.B Evidence of Uncertain Settlement

We argue that settlers faced considerable uncertainty surrounding their ability to obtain valid title to the land within the NP land grant, particularly from 1879-1894, but this did not deter all settlement, let alone patent activity. The dominant paths to land title in the West were Homestead, Cash-Sales, and direct purchase from Railroads. This was no less true for Montana. According to GLO patent data (BLM 2016), these categories account for over 75 percent of patents issued in Montana (see Table B3 in Appendix B). Railroad patents, though, do not necessarily indicate settlement. While railroads employed heavy marketing to sell these lands quickly (see Figure B4),[22] they (or their corporate heirs) also own vast estates years later (Jensen et al. 1995). But for the settler arriving to Montana between 1864 and, at a minimum, 1894, it was unclear if any path to title would constitute a valid title on odd-sections within the land grant. If one was to pre-emptively purchase a parcel from the railroad before the NP received a patent, the settler took on the risk that the NP, having violated the terms of the land grant, would never receive a patent. Settling under the Homestead Act or a cash-sale from the government was an equally dubious proposition as the NP could ultimately argue the land had been reserved in the grant and seek to confiscate improvements for their own gains, especially since the GLO had nominally withdrawn grant lands from settlement during this entire period.[23] We contend this two-sided uncertainty restrained investment, specifically in irrigation, in Montana. Shown in Figure 2, the completion of the NP did not incite a surge of patenting. Following an 1887 dispute in which the government favored a settler's claim over the railroad's (Powers 1889), patent activity increased slightly followed by further evidence of settlement near the end of 19th century as railroad patents were finally beginning to be clarified and issued.

Our empirical analysis requires some assumptions about the pervasiveness of uncertainty. For the first 9 years, settlers likely assumed the railroad would receive the lands and thus purchased on faith that the railroad would honor the arrangement and pass on the title once

[22] "These extremely productive lands stretch out for 50 miles on each side of the Northern Pacific Railroad […] Good water abounds all along the Northern Pacific […] there is a combination of soil and climate in the Northern Pacific which makes it the most reliable and productive wheat region in the world" (Rand McNally & Northern Pacific Railroad Co. 1883)

[23] WM A.J. Sparks, Commissioner of the GLO in 1885, contended that the office (and the broader government) had inappropriately withdrawn these lands prior to their appropriations, going as far as arguing the NP had not yet finalized their entire route, the required step for withdrawal, and as such, in his own opinion, no formal forfeiture act was required legally, but requested for it nonetheless to provide absolute clarity on the matter. (GLO 1885, pg. 26-46).

secured. Doubt likely crept in upon the NP's bankruptcy, growing considerably after the 1879 time limit passed without rail in Montana and throughout the 1880s as forfeiture acts gained steam. Notably, all the legal controversies we cite emerged during this period. After 1894, with (some) patents in hand and no more general forfeiture efforts mounted, uncertainty was curtailed, but the NP continued high profile land fights perhaps sufficient to give an investor pause.

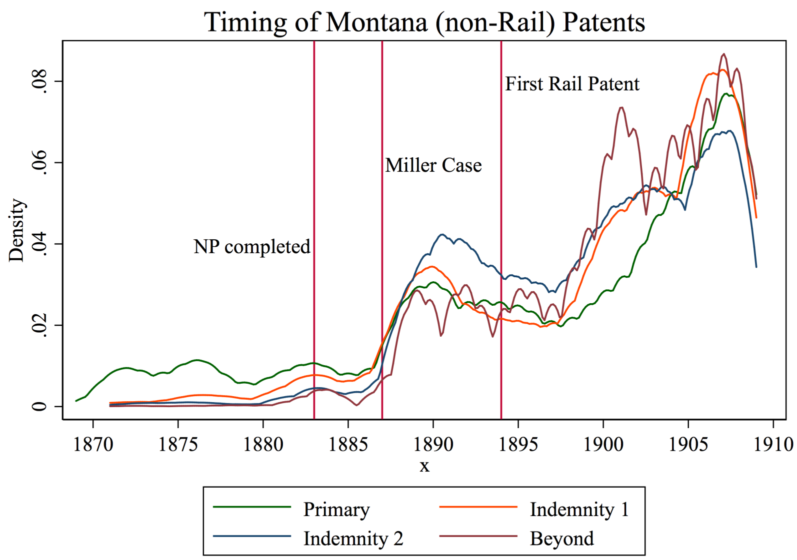
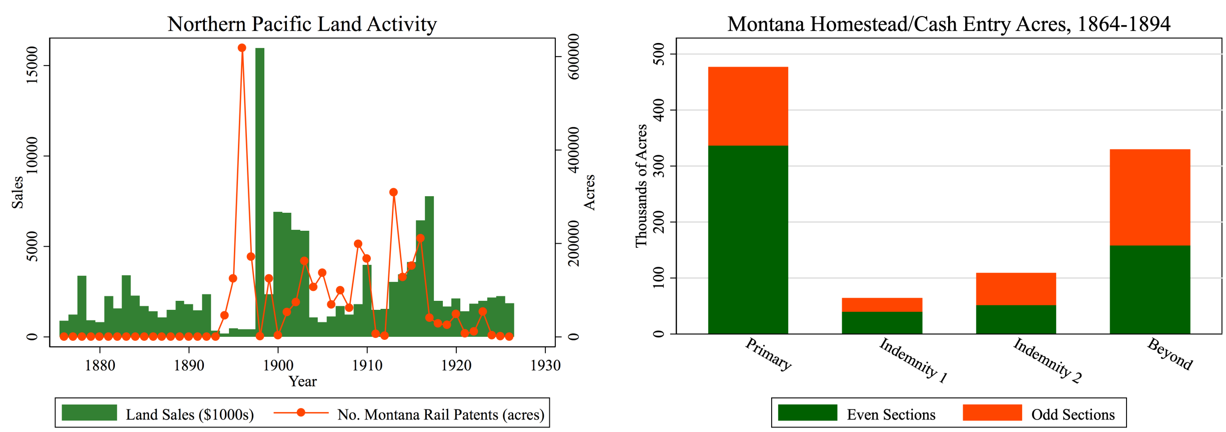


Figure 2: Non-railroad patents in Montana from 1870 to 1910.

Despite the uncertainty involved in both routes to settlement, we provide further evidence that some portion of settlers employed either approach (perhaps some settlers undertook both). In panel A of Figure 3 we show NP patents in Montana as well as NP land sales. As detailed above, the NP does not receive a single grant in Montana until 1894, before receiving a significant number in 1896. And while the most sales occur shortly after, a number of sales occur as far back as the 1870s. The sales data is for the entirety of the NP, so these may partly, or even wholly, be derived from grant lands in other states, but these also were not patented through 1891.[24] Panel B shows the incidence of homestead claims and cash sales (purchased from the U.S. Government) based on the location of the patent prior to 1894. In terms of overall location, many claims fall within the primary railroad grant during this period of uncertainty. Furthermore, though more even sections were claimed in the primary and first indemnity bands, some 25

[24] According to GLO land records, the only land patented under the NP Land Grant Statute prior to the 1890s was 3000 acres in Washington (1880). The NP first patented land in North Dakota in 1891, Oregon in 1892, Idaho and Montana in 1894, Wyoming in 1903 and Minnesota in 1908.

percent of patents were on odd sections, which were at least nominally reserved for the railroad. This indicates that 1) the GLO did not fully restrict access to these odd sections throughout this period, 2) settlers were willing to patent these sections, but 3) they were less able/willing to do so within 50 miles of the NP. In the second indemnity band and beyond, odd and even sections are claimed at nearly equal rates, as one would expect given the random nature of the PLSS grid.



Panel A **Panel B**

Figure 3: Northern Pacific Land activity. Net land sales and land sales are for the entire line while rail patents are for Montana only. Land sales come from Table C5 from Swenson & Gates (1968). Rail patents are from GLO records.

While the patent locations are illustrative of settlers seeking property rights, we focus our analysis on irrigation investment rather than patent date. For one, the patent data may not align with investment and economic development; homesteads necessarily were settled and "improved" 5 years prior to patent while purchases, be it from the railroad or the government, could remain undeveloped yet today. Second, the GLO was notoriously behind in surveying and processing claims forcing settlers to often occupy land absent patent.[25] Additionally, we do not observe sale price, which could capitalize in uncertainty, reflected by lower prices as seen in other uncertain natural-resource-based assets (e.g. Grainger & Costello 2014). Furthermore, in his 1885 annual report, the Commissioner of the GLO lamented that even a patent "from the United States to a settler under an award by adjudication of this department is not security to his rights against a railroad company" (GLO 1885, pg. 45). Instead, we rely on irrigation to capture

[25] Even through 1895, only 25.4 million acres had been surveyed, leaving some 66 million to go (GLO 1895, pg. 221). The Montana Surveyor General repeatedly call for more resources for surveys so that settlers "who are calling earnestly for such surveys, can secure titles to their lands; but to this matter I have so persistently called attention hitherto that it is hardly necessary to now enlarge upon it." (GLO 1885, pg. 363).

investment and development, noting that often priority years pre-date patent years for the same land; in Montana irrigation begins on average 10 years prior to the patent. Additionally, unlike the price of the land itself, the input costs to establish an irrigation ditch would not be able to adjust to reflect its risk of expropriation.[26] We hypothesize that irrigation development is less likely to occur on NP land grant land. We test whether this means a comparative development of irrigation on even-numbered parcels, all else equal. Or alternatively, due to the economies of scale appropriate for such investment, did the uncertainty to title deter investment to beyond the reach of the land grants entirely?

III. Empirical Analysis

In this section, we first describe the irrigation and land data with which we conduct two distinct econometric tests. Next, we describe and present the results for the two methodologies – difference-in-differences and spatial regression discontinuity – in turn. Finally, we bring in additional agriculture and irrigation census data and analysis to better quantify the extent to which the deterred investment we identify reduced agricultural development and diminished the aggregate economy of Montana.

III.A. Data

Our analyses utilize disaggregated spatial data with observations at the quarter-quarter PLSS unit (40 acres) which are spatially delineated by GIS files obtained from the BLM and Montana State Government.[27] In order to relate these units to measures of settlement and development, we have linked them to historic GLO patent records using PLSS identifiers, and irrigation records using state-maintained GIS shapefiles.

[26] Instead, the uncertainty made irrigation development a binary choice in a given location. Either invest a fixed amount in ditch construction, secure a priority date, and nonetheless run the risk of expropriation due to deficiency in land title; or incur these costs elsewhere where legal uncertainty was lower. This is the specific mechanism underlying how asset-specific investments are sensitive to uncertainty of title: the predominant margin on which to adjust such investments occurs ex-ante, making uncertainty of downstream rents of high importance before the asset-specific investment is “sunk”.

[27] Most homesteads were 160 acres and the sections received by the railroad were typically 640 acres. We opt for the 40 acres, however, because claims this small are observed in the patent data and agriculture/irrigation decisions are often made on the 40-acre fields. For instance, in Montana over 60 percent of the quarters (160 acres) that irrigate do so only on 40 acres or less. This does not imply economies of scale do not matter, as irrigating only 40 acres may make sense for farm production, but the irrigation infrastructure may still require a larger scale. On average, in 1919, an irrigation ditch in Montana served 307 acres across twelve 40-acre units. Still, standard errors in the analyses are adjusted to account for larger spatial patterns. We also conduct robustness checks at 160- (quarters) and 640-acre (sections) units.

Both Montana and Colorado maintain GIS shapefiles detailing what land is irrigated by which water rights.[28] The irrigated lands are linked to the water rights that serve the land, allowing us to measure the priority date. This provides a better proxy for settlement than the patent date because priority dates are based on when water is first diverted – signifying actual investment and development – and, since both states adopted the prior appropriation doctrine, irrigators were incentivized to ensure the date was correct since this determined their water availability. Colorado is limited to data from Water Division 1, which covers the South Platte basin and the Kansas-Pacific Railroad, due to availability and railroad presence. A full description of the data, including sources and variable construction, is provided in Appendix A.

Table 1: PLSS Summary Statistics

Second Division Summary Statistics

	Montana					**Colorado**					**Difference**
Variable	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	
Irrigation Development											
Irrigated	2,120,430	0.17	0.38	0	1	409,960	0.11	0.31	0	1	0.06
Irrigated by 1919	2,120,430	0.074	0.262	0	1	409,960	0.092	0.290	0	1	-0.02
Water Right Year	329,740	1925.65	34.37	1859	2017	40,022	1876.01	25.03	1859	1979	49.65
Water Right Year by 1919	156,794	1896.51	13.31	1859	1918	37,893	1871.04	14.00	1859	1918	25.48
Patent Data											
Patented	2,120,430	0.33	0.47	0	1	409,960	0.33	0.47	0	1	0.00
Patent Year	696,483	1917.94	16.81	1776	1999	136,178	1904.64	19.28	1800	2013	13.30
Controls											
Within Rail Land Grant (Primary)	2,120,430	0.40	0.49	0	1	409,960	0.40	0.49	0	1	0.01
Within Indemnity (1) or Primary	2,120,430	0.54	0.50	0	1	409,960	0.60	0.49	0	1	-0.06
Distance to Railroad (miles)	2,120,430	17.04	14.73	0	74.17	409,960	11.04	8.33	0	38.95	6.01
Strahler Stream Order (nearest)	2,120,430	1.63	1.13	1	6	409,960	1.50	0.89	1	5	0.13
Distance to Stream (meters)	2,120,430	1673.78	1429.49	0	6262.25	409,960	1797.18	1533.90	0	6262.24	-123.40
Soil Quality	2,120,430	5.30	1.69	0	8.01	409,960	4.91	1.61	0	7.01	0.39
Elevation (mean)	2,120,430	1219.94	480.21	573	3606	409,960	2023.23	703.70	1031	4267	-803.29
Elevation (st. dev.)	2,120,430	27.02	38.57	0	404.58	409,960	26.93	40.72	0	377.35	0.10

Note: Descriptive Statistics for 40 acre PLSS units in both Colorado and Montana. Colorado is limited to what is now Water Division 1 (North-East corner) due to limited irrigation data and railroad grant location. See Appendix A for a full description of the variables.

Outcome variables are summarized for Montana and Colorado in Table 2. As noted above, the observations are generally more numerous in Montana due to size, data availability, and railroad land grant activity.[29] Furthermore, in both states the measures for year (both patented and water right establishment) are conditional on settlement or irrigation respectively,

[28] These capture whether the land is capable of being irrigated. At any particular time, fewer acres will actually be irrigated given farm level cropping decisions as well as total water availability to the ditches.

[29] In addition, the samples are culled by limiting the sample to sections within the 95th percentile of distance from any stream in Montana (4 miles) to preclude areas that would be very unlikely to be developed for irrigation. In 1910, the average ditch length was just 1.4 miles, and this was seldom perpendicular to a stream (Edwards & Smith 2018). In Montana, we also removed irrigated acreage from the Flathead Reservation. These carry a priority date of 1855 due to the Winters v. United States, (207 U.S. 564, 1908) decision that granted water rights at the date of reservation. This large project in fact began construction in 1908 and continued through 1960 (Voggessor 2001). Our results are not sensitive to this decision (see Table B4 of Appendix B) and we also conduct robustness checks for other Indian Reservation effects.

making those samples smaller. Across the development outcomes Colorado settled earlier and developed more irrigation on average. On average, Colorado patents are 13 years earlier while Colorado water rights are nearly 50 years earlier. While we contend the lack of certainty over land ownership in Montana may have created this relative delay, our empirical strategy is considerably more conservative and focuses primarily on irrigation outcomes as they were in 1919.[30] Even with this restriction, Colorado still had 2 percentage points more of its land under irrigation and tended to do so 24 years earlier. It is notable that from 1859-1919, the average water right year in Montana is 1896, just after the first railroad patents were issued.

We gather and calculate a number of other variables that may influence the proclivity to invest in irrigation infrastructure. These are included in Table 2 as well. Most important are the variables capturing a land unit's proximity to railroads and land grants. Because the NP relied heavily on their indemnity bands (see Appendix B, Figure B5) and these were subject to uncertainty themselves, our main analysis draws on the land within 50 miles of the NP. In contrast, in Colorado these indemnity lands were not subject to uncertainty nor did the Kansas Pacific patent them extensively. Accordingly, we take "rail land buffer" in Colorado to be the 20 miles on either side of the rail line that made up the primary land grant. In subsequent analysis, we explore any distinctions between the primary and indemnity lands within Montana.

In addition to latitude and longitude, we gather information on the nearest surface water source, including the distance and size.[31] Soil quality provides a measure of the soil's suitability to agriculture, scaled from 1 to 8, with lower numbers being better. For elevation, calculated in meters, both the average and standard deviation (giving a measure of topography) are calculated at the section level (640 acres). The samples have similar measures for stream size and distance but with Montana having slightly larger and closer (or more) streams. Conditional on being irrigated, however, Colorado tends to extend much further with its irrigation investment. The

[30] We consider other time periods but use 1919 as our initial analysis for two reasons. First, by 1919, the NP had received 90 percent of the grants it ultimately receives in Montana, indicating some certainty that the railroad had received the land. Second, 1919 is the priority year for the Milk River project, a large Bureau of Reclamation project that brought many acres under irrigation primarily just beyond the NP land grant, potentially skewing the results for reasons independent of the railroad grant. Still, we conduct robustness at 1894 and 1941, two alternative dates of "certainty" as well as a flexible model that considers all the decadal years (1870, 1880, …, 2010).

[31] Size is imperfectly measured by Strahler order which scores stream reaches (portions of a stream hydrologically homogenous) from 1 to 7 (discretely) and increases as stream reaches come together. Specifically, when two streams reaches of the same order come together, the resulting reach's Strahler order is 1 higher than the separate streams. When two streams of differing orders come together, the resulting reach's stream maintains the Strahler order of the larger stream.

median distance away from a stream for irrigated land in Montana is 620 meters, while in Colorado the figure is nearly double that (1,122 meters). This is suggestive evidence that larger scale investments were less likely to occur in Montana, possibly owing to the general uncertainty of land rights and the need for pooling investments for more far flung irrigation projects.

III.B Method 1: Difference-in-Differences

To test our hypotheses that uncertainty surrounding railroad grants on the NP delayed and deterred irrigation investment and development, we analyze the outcomes within each state with more in-depth analysis of Montana. This results in a more specific estimate of the impact of the uncertainty by comparing only the irrigation investment decision within each state. This effect, while owing to uncertainty, only captures a relative impact and may understate or overstate the aggregate effect on development in Montana. Specifically, we run difference-in-differences regressions separately for each state, using Colorado to see how land grants can impact irrigation regardless of legal uncertainty. The regressions are cross-sectional, but we consider how odd sections within railroad land grants impact the timing and extent of settlement and irrigation vis-à-vis odd sections generally and beyond the railroad land grants. The regression equation is:

$$Y_{fsu} = \alpha \cdot Rail_u + \beta \cdot odd_s + \gamma \cdot Rail_u \times odd_s + \boldsymbol{\sigma}' \cdot \mathbf{F}_{\boldsymbol{f}} + \boldsymbol{\rho}' \cdot \boldsymbol{S}_{\boldsymbol{u}} + \varepsilon_{\mathrm{fsu}} \qquad (1)$$

Outcomes for 40 acre-units (u) in section s of township f considered include whether the land is irrigated by 1919 and the water right year. Because railroads themselves, independent of the land issues, provide numerous benefits of market access (both for inputs and outputs), we account for the later arrival of the Great Northern (1893) by adjusting the priority year to be relative to the completion year of the nearest railroad. We estimate equation (1) using OLS for both outcomes. Additionally, as a way to simultaneously explore whether and when land is settled or irrigated, we conduct a hazard analysis in which failure is the year when the land is first irrigated.

The two coefficients of interest are α, which estimates the impact of being within the railroad grant buffer, and γ, which is the estimated impact on an odd section within a railroad grant buffer. The underlying assumption is that the interspersed odd sections would have been equally likely to be irrigated as the even sections absent the legal uncertainty induced by the land grant. In general, the expected value of β is zero since an odd section outside of the railroad land grants should not be expected to be distinct from even sections barring small effects owing to even sections 16 and 36 being set aside for State use. Notably, we use odd sections and not actual railroad patents because we are not interested in the impact of railroad ownership but rather the uncertainty whether or not the railroads would receive these lands (and be able to legitimately sell them) or if settlement by other settlers would ultimately trump railroad claims in Montana.[32]

In addition to the variables of interest, we also include township ($\mathbf{F}_f$) and unit level ($\boldsymbol{S_u}$) covariates. Most notably, we directly control for distance (as a second order polynomial) from the nearest railroad. This helps to address the market access impact of being near a rail line (Donaldson and Hornbeck 2016) that is generally correlated with railroad land grant locations. Because we also consider the distinction between even and odd sections that are of similar distance, we do not expect this inclusion to have much effect on our estimates of interest. Still, in Montana, where the entire state is in the sample and the Great Northern also traverses the state but did not receive land grants, some identification of the rail access effect distinct from the land grant impact is garnered. Other unit level controls are latitude, longitude, distance to and size of nearest stream (with the second order polynomial of distance interacted with stream size to allow for non-linearities), and soil quality. For section level controls we include the average and standard deviation of elevation.

III.C Results 1: Difference-in-Differences

Regression results for PLSS unit outcomes are provided in Table 3. Strikingly, land within the railroad grant in Montana was considerably less likely to be brought under irrigation by 1919 while Colorado land within its railroad grant was much more likely to be irrigated. Given that land in Montana overall is only 7.4 percent likely to be irrigated in 1919, the reduction of 2.11 percentage points is quite large. Notably, this is inclusive of the even sections. That said, in Montana the odd sections within that area were less likely to be irrigated by an additional 0.5 percentage points, while there was no statistical distinction in Colorado. Together, this suggests that even sections in the NP grants were dissuaded from investing in irrigation and if they did invest, they often would do so without the neighboring odd sections, suggesting unrealized economies of scale and increased capital costs.

[32] That is not to dismiss the notion that railroad involvement may not have altered development (Hedges 1926; Zeisler-Vralsted 1993), but we do not use odd sections to instrument for railroad patents because our research question is not fundamentally about railroad ownership.

Table 2: Difference-in-Differences irrigation outcomes through 1919

	1919 Irrigation Outcomes					
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Irrigated (=1)		Priority Year		Failure=Irrigate	
Land Grant Buffer	-0.0211***	0.0207***	4.218***	0.716	-0.145***	-0.0419
	(0.00178)	(0.00427)	(0.330)	(0.662)	(0.0241)	(0.0593)
Odd Section	0.00112	-0.000411	0.228	-0.00311	0.0195	-0.00699
	(0.00146)	(0.00265)	(0.299)	(0.678)	(0.0246)	(0.0623)
Land Grant Buffer x Odd Section	-0.00538**	0.00159	-0.604	-0.0212	-0.0736**	0.0222
	(0.00220)	(0.00599)	(0.407)	(0.749)	(0.0329)	(0.0754)
Distance to Rail	-0.00148***	-0.0253***	0.213***	0.247**	-0.0124***	-0.309***
	(0.000115)	(0.000590)	(0.0211)	(0.117)	(0.00180)	(0.00884)
Distance to Rail^2	1.31e-05***	0.000617***	2.48e-05	0.0419***	-2.49e-05	0.00545***
	(1.82e-06)	(1.71e-05)	(0.000441)	(0.00567)	(3.46e-05)	(0.000369)
State	MT	CO	MT	CO	MT	CO
Model	OLS	OLS	OLS	OLS	Hazard	Hazard
Observations	2,120,430	409,960	156,794	37,893	2,120,430	409,960
R-squared	0.079	0.327	0.088	0.614		

Note: Regression Results for PLSS Second Division Land Units (40 Acres). Land Grant Buffer indicates that the unit is within the designated distance from the railroad to be in the land grant area (50 miles for Montana, 20 miles for Colorado). Odd Section indicates that the unit is contained in an odd section. Railroad distance is in miles from the nearest railroad line (not necessarily the Northern Pacific or Union Pacific). Additional unreported controls include latitude and longitude, distance (and distance squared) to and size of nearest stream, soil quality, and the median and standard deviation of the elevation for the section. Robust standard errors, clustered by section, in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Turning to the priority year, marking the date of investment, water rights tend to be 4.2 years later within the railroad grant in Montana than the land beyond it. Colorado grants experienced no similar delay. Likely related to the economies of scale, conditional on being irrigated, there is no evidence of further delay for odd sections within the grants in either state. In other words, irrigation projects were not well-suited for checkerboard ownership and relied on ownership across the grid being settled, so the uncertainty on the odd sections was sufficient to also delay investment on the neighboring even sections. Finally, the hazard model, which considers both the likelihood of irrigation and when it occurs, provides similar evidence. In Montana, land grant land (odd sections) was around 22 percent less likely to be brought under irrigation in any given year relative to land beyond while even sections within the grant were still 14 percent less likely to be irrigated. In table B5 of Appendix B we show that the results for Montana are robust to selection of covariates, exclusion of "small" irrigation, aggregating observations to the quarter (160 acres) or section (640 acres), and using a logit (for irrigated) or tobit (fraction irrigated).[33]

The proclivity to invest and bring land under irrigation is not especially sensitive to the 1919 cutoff within the land grants in Montana. In Appendix B we conduct analysis for 1894 (the first patent granted to NP) and 1941 (when indemnity land dispute was settled by the US Supreme Court) as the specific alternative dates of reduced uncertainty. More broadly, however, Figure 4 further unpacks the time component, plotting the coefficient for the land grant buffer when estimating equation (1) for snapshots at decadal time-steps (1870-2010). Notably, the area in the land buffer was only slightly less likely to be irrigated in 1870 and 1880. It is doubtful that in 1870 any doubts over the land grants were present as the NP had begun construction, not yet gone bankrupt, nor missed the statutorily set timeline. Even in 1880, the railroad forfeiture acts had not yet occurred, though certainly doubts were creeping in. From 1890 onward, however, the land grant land is persistently less likely to be irrigated.

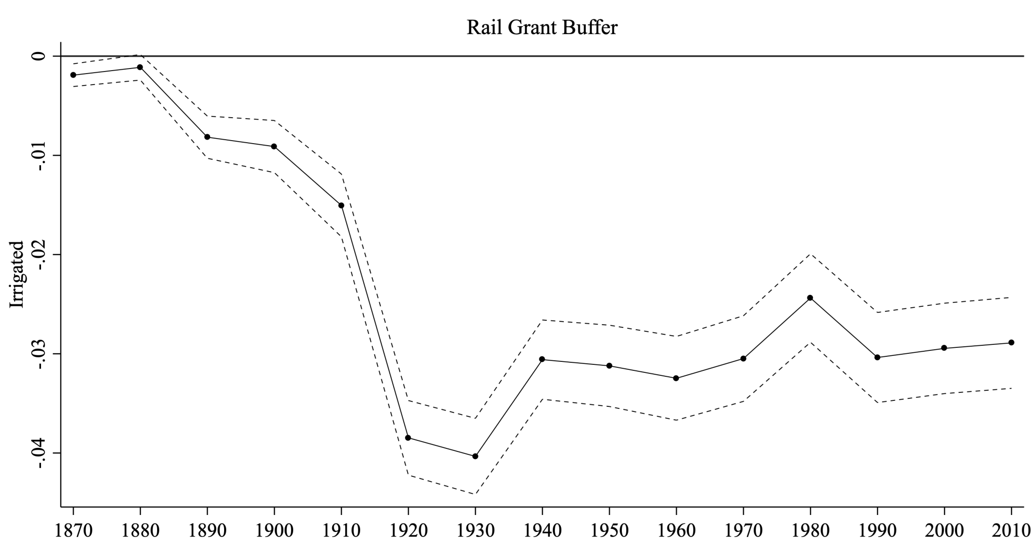


Figure 4: Estimated coefficient on the Land Grant Buffer. Each coefficient comes from a separate regression in which the outcome is whether the plot is irrigated by that year. Regressions are OLS, standard errors are clustered by sections.

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[33] We also test for a distinct effect across the primary lands and indemnity lands in Montana by including an additional indicator for whether the land is within 40 miles of the NP and its interaction with odd sections (See Appendix Table B6). Across the indemnity and primary lands, there is no statistical distinction for the amount of the land units brought under irrigation or the hazard through time of being brought under irrigation. The primary land, however, is slightly more delayed in time for those areas that are irrigated. We also explicitly control for being within 50 miles of the Great Northern in another robustness check (Appendix Table B7), finding the odds of irrigating are greater in this band, suggesting railroads, absent tenure security issues, are indeed attractive.

Throughout the difference-in-differences analysis, the negative effect is dominantly on the entire land grant, not just the odd sections. One explanation are the economies of scale for irrigation projects, which meant the uncertainty over the odd sections bled over to the adjacent even sections, holding up or precluding irrigation development there as well.[34] However, this fact also means our identifying assumption for this analysis is weaker than supposed, a potential issue raised about checkerboard identification strategies when neighboring parcels in fact influence productivity decisions (Leonard & Parker 2019). Absent the randomization of the odd and even sections, it is less obvious that the NP land grant buffer was itself entirely random or similar to the remainder of Montana, meaning other correlated factors, not just legal uncertainty, could partially explain the lower levels of irrigation.[35] Nonetheless, we believe our covariates cover many alternative explanations (particularly for the 1880-1900 decline), and that the railroad would have most probably pushed for a route primed for settlement (we demonstrate below that irrigated acres within the land grant were 50 percent more valuable than irrigated acreage elsewhere in Montana as of 1930).

An alternative explanation is that uncertainty prevailed because settlers may have been aware of their distance from the NP, but absent survey, clueless as to their land's position in the grid.[36] This is to say the lack of survey created uncertainty across the entire grant, even on what were ultimately "secure" even sections. Still, without the randomization of the grid to instrument for uncertainty, some doubt lingers we have a clean causal estimate. For instance, the continued relative decline from 1910 to 1920 is likely spuriously related to Milk River Project which brought 121,000 acres under irrigation beyond the land grant, but not likely because of the land grant.[37] Accordingly, to further assess the causal role of the uncertain land grant, we turn to a second identification strategy.

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[34] Indeed, among his series of placebo tests in Wyoming relative to state-owned lands, Lewis (2019) found irrigation to be one outcome exhibiting spatial spillovers, though he did not discuss the pooled-investment mechanism.

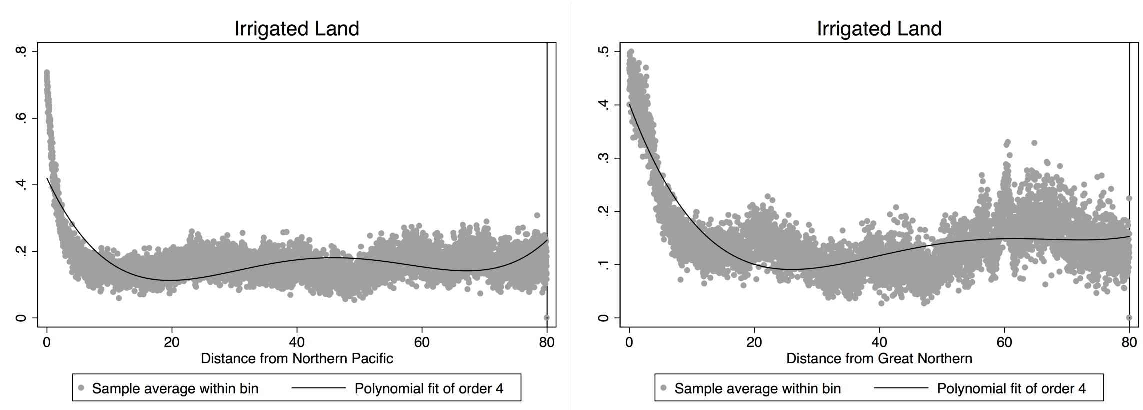
[35] See Appendix B, Table B9 for a balance table of variables for NP land grant and the rest of Montana. On balance, the areas were similar but if anything, the land grant was arguably more suitable for irrigation.

[36] A contemporaneous New York Times article about Montana raised this very issue, stating, "[i]f a claim was located, and on the survey it proved that it was a railroad section, it must be purchased from the company or held under a clouded title. The delay in surveying the grant, had, accordingly, further retarded the development of the country." (New York Times, 1892).

[37] An additional source of "uncertainty" in Montana could be the extensive Native American populations and reservations. In 1880, 32 percent of the state was set aside in reservations, although by 1915 merely 6 percent remained set aside. While interesting to study in its own right (see Taylor 2019), for our purposes we have run a robustness test, presented in Table B10 of Appendix B, which controls for whether the unit of land is within a reservation in either year (data provided by Taylor 2019). Interestingly, being in a reservation in 1880 improves the

III.D Methods 2: Spatial Regression Discontinuity

One difficulty of identifying the effect of land grants on settlement and investment is that railroads, providing greater access to markets and/or building routes nearer to desirable land, are necessarily collocated. In our above analysis we address this to some extent by including a polynomial for the distance from the rail and relying on the Great Northern to help identify this separate effect. However, comparing lands immediately adjacent to the rail line to those 51 miles away may be problematic despite the covariates. Indeed, Figure 5 below suggests that land nearer to either railroad in Montana is more attractive for irrigation.



Panel A **Panel B**

Figure 5: Propensity to irrigate eventually.

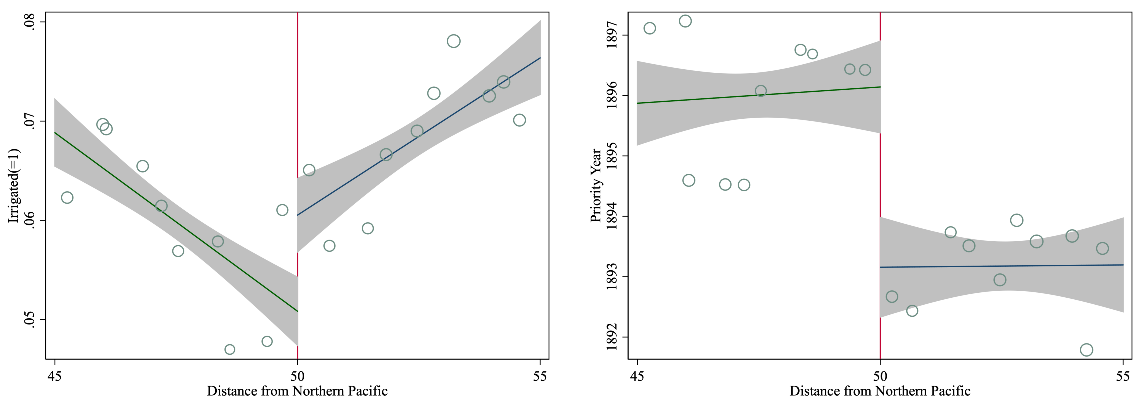
As an alternative identification strategy, we present analysis from a spatial regression discontinuity, narrowing in on land just within and just beyond the statutory limits of the land grant to address selection issues. Given the number of observations and statutorily-determined rather than attribute-determined extent of potential grants, our data is well suited for this empirical technique. The analysis continues to focus on the 50-mile distance for the NP with some consideration of the 40 (primary) and 60 (second indemnity band) as well. Figure 5 above generally suggests that the advantage of the railroad transportation (or alternatively, the irrigation along the nearby larger streams – Missouri and the Yellowstone) dissipates beyond 10 miles or so.[38] At 50-miles, these lands were further removed from the benefit of the railroad transport and the large streams which the railroads tended to follow. However, smaller streams populate the

odds of irrigation by 1919, but this is driven by land no longer included in the reservations by 1915. Our main estimates remain robust to this inclusion.

[38] Fogel (1966) in his seminal work suggested 40 miles was a reasonable limit beyond which the benefits of transportation networks were considerably muted.

landscape that could appeal to the entrepreneurial irrigator compelled to settle further afield due to the uncertain status of the land closer to the railroad.

The estimates employ the rdrobust command in Stata (Calonico et al. 2017) that selects an optimal bandwidth trading off between bias and variance.[39] But first, suggestive evidence that the railroad grants mattered are provided in Figure 6 below which plots the simple linear fit for the year of irrigation for units within 5 miles of either side of the first indemnity band border in Montana. There appears a stark change at the border and actual irrigation investment occurs years earlier just beyond the railroad grant lands in Montana.



Panel A **Panel B**

Figure 6: Linear fit of year of irrigation of PLSS units (40 acres) by distance from the Northern Pacific. Panel A whether the unit is irrigated by 1919; Panel B is the year of irrigation conditional on irrigation prior to 1919. Separate fit lines and their 95% confidence intervals are shown for 45-50 miles and 50-55 miles.

The regression discontinuity method assumes that, other than the change in policy imposed by the distance, the land on either side of the cutoff is similar along other dimensions. In testing this assumption for covariates utilized in our difference-in-differences analysis – stream size, distance to stream, soil suitability, elevation, and elevation variation – we found no statistical distinction (results in Appendix B, Table B11).

III.E Results 2: Spatial RD

Results, considering whether the land is irrigated and if so, when, are presented in Table 3 for each of land grant limits (40, 50, and 60 miles) along the NP. Just within the primary grant buffer, the share of parcels irrigated by 1919 decreases by 0.00909. Though somewhat small, of

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[39] Some robustness checks employ the linear OLS approximation ($Y_{fsu} = \alpha \cdot |dist_{50}|_u + \beta \cdot |dist_{50}|_u \times Inside_{50_u} + \gamma \cdot Inside_{50_u} + \boldsymbol{\sigma}' \cdot \mathbf{F}_f + \boldsymbol{\rho}' \cdot \boldsymbol{S}_u + \varepsilon_{fsu}$) with observations limited to those within range of the threshold.

land within 3 miles of the primary land grant border, only 0.06 are irrigated by 1919. This means that parcels just outside the primary lands were 15 percent more likely to be irrigated. There is no statistical distinction in the timing of irrigation. At the edge of the first indemnity band, the parcels just beyond are more likely to be irrigated and brought under irrigation around 4.3 years earlier than parcels within the first indemnity band. Across Montana during this period, the standard deviation of priority year is just 15 years, so this delay amounts to 29 percent of one standard deviation. Finally, at the edge of the second indemnity band, there is no distinction in the rate of irrigation, but just beyond the totality of the NP's possible claim, irrigation does occur 2.5 years earlier. On net, each discontinuity suggests irrigators preferred more certainty, choosing to irrigate more and/or earlier just beyond the boundaries even when the land and market access were similar.[40] Once again, the strongest evidence of delayed and deterred investment is at the edge of the first indemnity band and we focus our numerous robustness checks on this boundary.

Table 3: Spatial RD results for the Northern Pacific, various distances

Regression Discontinuity Irrigation Results, Northern Pacific

	(1)	(2)	(3)
VARIABLES	Primary	Indemnity 1	Indemnity 2
Panel A: Irrigated			
Discontinuity (within)	-0.00909**	-0.00750***	0.000158
	(0.00383)	(0.00282)	(0.00329)
Observations	1,420,745	1,420,745	1,420,745
Bandwidth	2.959	4.698	4.040
Panel B: Priority Year			
Discontinuity (within)	-0.0157	4.336***	2.489***
	(0.512)	(0.499)	(0.710)
Observations	114,016	114,016	114,016
Bandwidth	4.310	8.109	3.201
Distance from Northern Pacific	***40***	***50***	***60***

Note: Results are for the change in the dependent variable (measured in 1919) at 40, 50, and 60 miles away from the Northern Pacific Railroad. Estimates come from the rdrobust command in Stata. Observations include only PLSS sections within 80 miles of the Northern Pacific in Montana. Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

[40] It should be mentioned that the economies of scale issue present in the difference-in-differences approach could also be present here. i.e. parcels just beyond the grant would also neighbor "uncertain" parcels. We note, however, that only those immediately abutting the grant would experience this and they would still have 3 adjoining sections to coordinate with rather than zero. Furthermore, this concern would bias our estimates towards zero.

In Table 4, we provide a series of placebo tests for discontinuities relative to railroads where there is no change in certainty. First, in panel A we look for a differential effect along the NP at the (arbitrary) 20-mile mark and find insignificant effects for irrigation investment, both statistically and in magnitude. In Panel B we ensure there is nothing oddly special about being 50 miles away from a transcontinental railroad in Montana by looking at the effect at that distance from the Great Northern. Again, the results are small and insignificant. Finally, we return to Colorado and assess if there is reason to believe that the edge of land grants induces this variation in irrigation independent of any legal uncertainty surrounding the grants. Once again, there is no impact on the decision to irrigate, but we do find that parcels within the grant are irrigated 2.3 years *earlier*.

Table 4: RD Placebo Tests

Regression Discontinuity: Placebo Tests

VARIABLES	(1) Irrigated	(2) Priority Year
Panel A: Northern Pacific (MT)		
Discontinuity (20 Miles)	0.00215	0.703
	(0.00389)	(0.595)
Observations	1,420,745	114,016
Bandwidth	2.033	3.787
Panel B: Great Northern (MT)		
Discontinuity (50 Miles)	-0.00682	0.893
	(0.00522)	(1.059)
Observations	696,529	39,844
Bandwidth	2.761	3.203
Panel C: Union Pacific (CO)		
Discontinuity (20 Miles)	-0.00119	-2.329*
	(0.00336)	(1.351)
Observations	290,611	13,720
Bandwidth	3.801	2.933

Note: Results are for the change in the dependent variable (measured in 1919) at edge of the railroad land grants. Panel A uses 20 miles from the Northern Pacific as the cutoff. Panel B is for the Great Northern Railroad (excluding observations overlapping with NP land grant). Panel C is for the Union Pacific. Estimates come from the rdrobust command in Stata. Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Next, we present Figure 7 which, like Figure 4 above, shows estimated coefficients for the effect at decadal time-steps to provide a visual of the dynamics over time. Irrigation occurred at nearly the same rate from 1870 to 1880, but experienced a sharp relative decline within the land grant between 1880 and 1890 amid the numerous attempted forfeiture acts. In contrast to the difference-in-difference analysis above, no further decline is found in 1920, consistent with that effect being driven by the Milk River Project and not continued uncertainty. However, persistence of the detrimental effects of the initial uncertainty lingers through today.

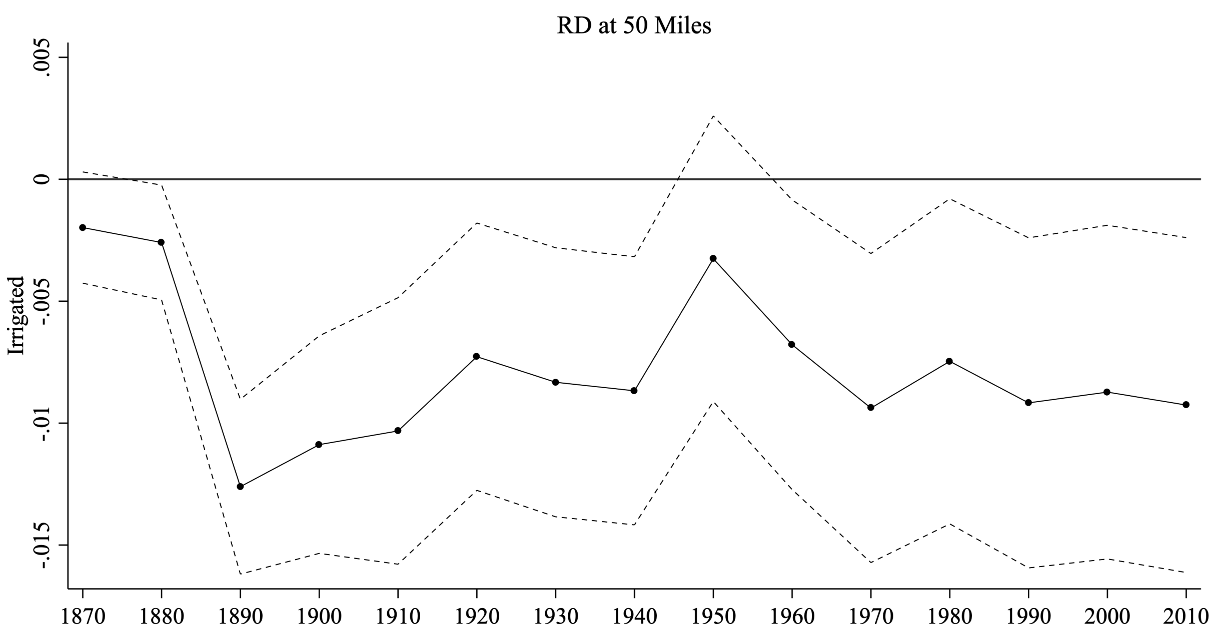

Figure 7: RD estimates for the edge of the Northern Pacific Land Grant. Each coefficient is from a separate estimation with irrigated or not (at that time) as the outcome variable forcing all to use a 5-mile bandwidth.

A series of robustness checks at the 50-mile discontinuity are provided in Appendix B, Tables B11-B15. We test the robustness of the main RD specification with the inclusion of covariates, different bandwidths (1, 5, 10, 15, and 20 miles), various local polynomial orders (2, 3, and 4), and testing even sections only, as well as a hazard model-based estimate. Results are similar across nearly all. The one notable distinction is that we cannot reject that even sections were equally likely to be irrigated, but they were still delayed nearly 5 years.

Table 5: RD Border Location Robustness

Regression Discontinuity: North/South				
	(1)	(2)	(3)	(4)
VARIABLES				
Panel A: Irrigated				
Discontinuity	-0.0105***	-0.0144*		
	(0.00224)	(0.00745)		
Discontinuity (North)			-0.0132**	-0.0138**
			(0.00602)	(0.00582)
Discontinuity x South			0.00409	0.00701
			(0.0177)	(0.0155)
Observations	810,498	610,247	125,038	125,038
Bandwidth	5.301	3.353	4.3	4.3
Panel B: Priority Year				
Discontinuity	8.980***	3.640***		
	(0.927)	(0.983)		
Discontinuity (North)			10.88***	7.995***
			(2.319)	(2.214)
Discontinuity x South			-9.669***	-8.001***
			(3.192)	(2.521)
Observations	53,998	60,018	7,945	7,945
Bandwidth	5.253	3.362	4.3	4.3
North/South Indicator	N	N	Y	Y
East/West 10-Mile Indicators	N	N	N	Y
Border	North	South	Both	Both

Note: Results are for the change in the dependent variable at 50 miles away from the Northern Pacific Railroad. Estimates for columns (1) and (2) come from the rdrobust command in Stata. Columns (3) and (4) are OLS estimates to allow for the differential effect along the North and South border as well as the inclusion of numerous indicator variables from east to west. Observations include only PLSS sections within 80 miles of the Northern Pacific in Montana.
Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Last, because Montana is vast and the NP land grant within extends some 500 miles east to west while its two distinct borders lay 100 miles apart, we present one final robustness check (Table 5) that accounts for this variation. First, we run the regressions for the northern border and southern border separately. Along both borders, the reduction in irrigation investment is similar. However, there are indications that in terms of the delay the northern border was lagged nearly 9 years while the southern border was delayed closer to 3 years. For columns (3) and (4) we put both borders back in the sample, but allow for the effect to be different at each border.[41] As with the separate samples, there appears to be no distinction between the two borders on the lower

[41] rdrobust does not allow for this. To accommodate this, these specifications are estimated using an OLS version of the regression discontinuity with observations limited to 4.3-miles within either border. An indicator term for "south" is interacted with the within 50-mile indicator as well as the linear trends on each side of the border.

proclivity to invest in irrigation, but the delay is more severe at the northern edge (and perhaps negligible on the southern border). Finally, drawing on inspiration from Mian et al. (2015), we include indicator variables for each 10-mile section east-to-west interacted with the south border indicator to account for distinctions along the long spatial RD borders. Therefore, the identification is within each 10-mile strip of each border, accounting for differential railroad completion and other factors that generally differ from eastern to western Montana as well as northern and southern Montana. The results, presented in column (4), are robust to this inclusion.

III.F Costs to the Montana Economy

Both methodologies, exploiting different sources of identification, suggest a substantial deterrence and delay of irrigation investment within the NP land grant in Montana relative to similar areas beyond the grant. Meanwhile, along the GN, which received no land grant in Montana, and along Colorado land grant areas, no similar effects were found. The effect along the NP emerges strongly between 1880 and 1890, the decade when the NP land grant experienced its greatest political uncertainty. Taken together, our results make a compelling argument that legal uncertainty stymied irrigation development within the state of Montana. Furthermore, our empirical examination indicates the effects persisted even after the uncertainty abated.

By combining our empirical results with US agriculture and irrigation census data from 1920 and 1930, we can estimate how costly the delayed and deterred irrigation was to Montana's economy (the full details are laid out in Appendix C). Our main difference-in-differences estimates predict that 234,630 fewer acres were irrigated within the land grant by 1919.[42] In addition, the 765,283 acres within the grant irrigated were delayed on average by 4.22 years. The cost estimates depend on the counterfactual. We consider whether the land that was not irrigated within the land grant remained unfarmed or if dry-land farming occurred and whether the irrigation investment was displaced to a second-choice location beyond the land grant or

[42] Even sections within the grant were 2 percent less likely to be irrigated than even sections beyond according to our estimates. To arrive at the non-irrigated (even) acreage, we took this coefficient and multiplied it by the number of even sections in the land grant, then multiplied that product by 40 acres. Recognizing that the entire 40 acres was seldom irrigated, we further multiply the figure by the observed average number of irrigable acres of irrigated sections (0.59). Furthermore, because our measure of "irrigation" aligns with the acreage within an irrigation enterprise, we multiply by the average irrigated acreage per acre in an irrigation enterprise in 1920 (0.39). We repeat the process for odd sections, which were 2.4 percent less likely to be irrigated within the grant. Similar conversions were made to account for the extent that was irrigated in the land grant. See Appendix C for a full accounting.

completely deterred. While dry-land farming and displaced irrigation would offset some of the implied losses, both are less valuable than irrigation within the land grant. This is evidenced by the fact that non-irrigated crop land yielded only 55 percent per acre as irrigated acres in 1919 (US Bureau of the Census 1922, Montana, Table 18)[43] and that irrigated farms were 51 percent less valuable per acre beyond the land grant in 1930 (US Bureau of the Census 1932a).[44]

In Table 6, we provide calculations covering the various counterfactuals (in 2015 dollars). Following Leonard & Libecap's (2019) recent estimates for the gains of prior appropriation over the riparian doctrine in Colorado, we apply Fogel's (1964) social discount rate of 7.91 percent when moving between net present values and annualized amounts. The largest estimated cost – in which the deterred irrigation is not attenuated in any way – is a $2.8 billion reduction of NPV, or 27.3 percent of total farm value (land and buildings) in Montana at the time. If, instead, the lack of irrigation meant dry-land farming – which is still $2,076.45 less valuable per acre than irrigated land on an NPV basis once costs of irrigation are accounted for – the losses are reduced to 10.6 percent.

For displaced irrigation the 1919 irrigation census data is insufficient because irrigated value is only reported at the state level, providing no spatial variation. Instead, we utilize county level data from 1930 which differentiates farm values by whether or not they are irrigated (Haines 2010). First, using these figures and our estimates for deterred and delayed acres, we re-calculate the losses assuming no displacement to compare to the 1919 estimates.[45] This methodology results in lower estimates, particularly as measured in dollars, but we note that the per-acre farm values in Montana were 43 percent lower in 1930 than in 1920, so we emphasize

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[43] Specifically, we utilize Montana irrigation data from 1919. Table 18 provides the market value for specific crops bifurcated by irrigation status. We calculate the average irrigated crop land produced $478.50 worth of crops whereas non-irrigated land yielded $288.22 per acre. Recognizing that irrigation is costly, we subtract off the annual per acre cost of irrigation maintenance reported in table 10 ($17.36). We then calculate the NPV of this annual net revenue. Finally, we subtract off the irrigation capital investment per acre reported in table 8 ($260.96). For delayed irrigation, we find the NPV loss of irrigated crop production for 4.22 years but also adjust for the capital investment being delayed 4.22 years. These figures are then multiplied by the number of acres our estimates suggest were affected.

[44] We first calculate the fraction of each county that lies within the 50-mile buffer surrounding the NP. We then regress the average farm value per acre for irrigated farms on this variable (US Bureau of the Census 1932a, Irrigation Census, County Table, pg. 147—Digitized by Haines 2010), finding that values are 51 percent larger within the buffer. We repeat this for non-irrigated farm values per acre, finding they are 5.6 percent more valuable within the buffer. Results of these analyses are provided in Appendix C, Table C1.

[45] We use 1930 irrigation rates on land served by irrigation enterprises (0.61) to convert our estimates to actual irrigated land losses. Because the 1930 values are reported for farm acres per irrigated farm (not per irrigated acre), we draw on the average irrigated acres per irrigated farm to scale our irrigated acreage (13.3 percent) to estimate the number of farm acres implicated.

the percent of total value over the actual amounts.[46] These percentages are still slightly smaller, but still account for 18.1 percent if no farming occurred and 6.9 percent if dry-land farming occurred in irrigation's stead. Finally, we conduct the counterfactual that all of the deterred irrigation investment was completely offset by irrigation investment beyond the uncertain grant lands, but within Montana. Given that farm values were higher nearer to the NP, this still resulted in losses of 7.2 to 12.0 percent, depending if dry-land crops were grown in place of irrigated crops.[47]

Table 6: Counterfactual Cost Estimates

NPV Cost Estimates (2015 Millions $)

Counterfactual		**No Investment**		**Displaced Investment**
		1919 Method	**1930 Method**	**1930 Method**
No Crops	Deterred	$1,399.35	$844.79	$403.81
	(Percent)	13.2%	11.6%	5.6%
	Delayed	$1,431.15	$471.37	$471.37
	(Percent)	13.5%	6.5%	6.5%
	Total NPV Loss	$2,830.50	$1,316.17	$875.18
	(Percent)	26.7%	18.1%	12.0%
Dry-land crops	Deterred	$486.85	$323.34	$340.60
	(Percent)	4.6%	4.4%	4.7%
	Delayed	$634.02	$180.41	$180.41
	(Percent)	6.0%	2.5%	2.5%
	Total NPV Loss	$1,120.88	$503.75	$521.01
	(Percent)	10.6%	6.9%	7.2%

Note: 1919 method scales our estimated impact on irrigated land by the net value of crops on irrigated land. The 1930 method scales our estimates by the value of land in irrigated and non-irrigated farms, spatially differentiated across Montana counties. Percent is in terms of the total farm value in Montana reported in the 1920 and 1930 censuses respectively. Details on calculations provided in the text and Online Appendix C.

Overall, we find that the uncertainty imposed considerable losses to the agriculture sector of Montana. Even in the most conservative calculations, 6.9% of farm value is absent. In terms of the wider economy, if we annualize the losses and compare to Montana's entire state income

[46] See Table 20, 1930 Agriculture Census Volume 4: Farms and Farm Property (US Bureau of the Census 1932b). This trend is true for the entire United States (28 percent decline). The inter-war period witnessed depressed earnings and numerous farm foreclosures (Alston 1983).

[47] We assume that delayed irrigation was not displaced during the delay, meaning the delay costs are the same for both 1930 methods. We also note that dry-land crops did not ameliorate the losses in the case of displaced irrigation. This is because, according to our estimates, even non-irrigated farms within the land grant were more valuable than irrigated farms beyond the land grant.

in 1930 ($3.5 billion according to Leonard & Libecap 2019 calculations, Table 3), the annualized losses range from 1.04 percent to 5.83 percent of state income. These calculations demonstrate that the uncertainty induced by the NP land grant created significant economic losses relative to the counterfactual.

IV. Conclusion

Utilizing the massive NP land grant in Montana and its tumultuous history as a natural experiment, we identify a causal effect of land title uncertainty on asset-specific investment. Irrigation infrastructure, critical to agricultural development in the region, was 28 percent less prevalent within the land grant where uncertainty prevailed from 1879-1894, at a minimum. What land was irrigated tended to be done so 4.2 years later despite the market access provided by the NP line itself. Though the uncertainty pertained only to odd-numbered sections, we find that even-numbered sections also lacked development owing to their limited ability to successfully coordinate with their affected neighbors. These results underscore the economic costs of lingering title insecurity along frontiers, historic or contemporary, once the demand for title has emerged. Although the appropriate role for the government in defining property rights remains a question worthy of further consideration, our analysis suggests that the ideal role for the government in securing title is to first do no harm – government practices that create uncertainty can observably stymy the beneficial development of property. In addition, our specific context and results uncover an economic cost that has not yet entered the retrospective ledger book of the costs and benefits of the railroad land grants.

Our line of investigation has also prompted additional related questions. Were other natural resources and their development (e.g. minerals or timber) similarly impacted by uncertainty around land grants? To what extent did land grants more generally temper the gains the railroads themselves provided? We leave these for additional research, but our results suggest that in a period of well-recognized fraud and corruption as between the railroads and the government, such a rapid handout of public lands was not without its losses. However, this is not to say the NP nor its land grant was a net loss for Montana. If without the land grant no line would have been constructed, or only constructed much later, irrigation development (and broader development) might have been even further delayed. Rather, we show that the *uncertainty* of ownership related to the land grant derailed some development the railroad ushered in and, more generally that insecure property rights can cause a large reduction in asset specific investment.

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Development Derailed: Uncertain Property Rights and Asset-Specific Investment

Appendix A: Data and Variables Description

Here we describe the variables and underlying sources for all data surrounding the main analysis. For details on the cost estimates that employ additional US Census data, see appendix C.

A.1 Raw Data Sources:

Bureau of Land Management (BLM). *Colorado PLSS Second Division.* 2016a. [accessed April 2016] http://www.blm.gov/co/st/en/BLM_Programs/geographical_sciences/gis/GeospatialData/gcdb_mm_2005_polygon.html

Bureau of Land Management (BLM). *General Land Office Records.* 2016b. [accessed September 2016] https://glorecords.blm.gov/search/default.aspx?searchTabIndex=0&searchByTypeIndex=0

Colorado Information Market Place (CIMP). *DWR Water Right – Net Amounts. 2016* [downloaded September, 2016] https://data.colorado.gov/Water/DWR-Water-Right-Net-Amounts/acsg-f33s

Colorado's Decision Support Systems (CDSS) *GIS Data; Irrigated Lands (Division 1, 1956)*. 2016. [downloaded August 2016] http://cdss.state.co.us/GIS/Pages/AllGISData.aspx

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USDA NRCS. *Digital General Soil Map of U.S.: Tabular digital data and vector digital data.* Fort Worth, Texas, 2006. http://websoilsurvey.nrcs.usda.gov

USGS EROS Data Center. *GTOPO30 global digital elevation model: raster data tiles.* Sioux Falls, South Dakota, 1996. https://lta.cr.usgs.gov/GTOPO30

A.2 Variables in Main Analysis:

OUTCOMES:

Irrigate[year]: An indicator equal to 1 if any portion of the 40-acre unit has irrigated land from a surface ditch by the [*year*] indicated. Measure is calculated in ArcGIS using shape files from Montana (MTDNRC 2017, MSL 2016) and Colorado (CDSS 2016, BLM 2016a). After reducing the water rights data to the purpose of "irrigation", we tabulated the intersection between the irrigation service area and each 40-acre unit. The indicator variable is set to 1 if the fraction of the PLSS unit contained in an irrigation ditch service area is greater than zero.

Water Right Year: Year of the ***earliest*** water right irrigating the 40-acre unit. For Montana the data came directly from MTDNRC (2017) based on the water right associated with the irrigated land. In Colorado the water right was spatially joined to the land using CDSS (2016) and then linked to water right information provided in CIMP (2016). For the difference-in-differences analysis, this was adjusted to be relative to the completion of the nearest transcontinental railroad.

CONTROLS:

Distance to Railroad: This is the distance in miles from the nearest railroad. Distances were calculated in ArcGIS with the near table tool using ESRI (2016) and PLSS shape files (MSL 2016, BLM 2016a). Distances were also calculated separately from the railroads of interest (Northern Pacific, Union/Kansas/Colorado Pacific, and the Great Northern) for units up to some distance beyond the indemnity band (CO=40 miles, MT=80 miles).

Land Grant Buffer: This is an indicator equal to 1 if the centroid of the 40-acre unit lies within the statutorily defined extent of the relevant railroad based on the distance calculation. In our main analysis we consider all sections within the primary and first indemnity band in Montana (50 miles) and within the primary band of Colorado (20 miles). We also create a similar measure for 40-acre units within 50 miles of the Great Northern even though no land was granted. In addition, we maintain distinct indicators for whether the unit is in the primary band, first indemnity band, and second indemnity band for robustness checks.

Odd Section: This is an indicator equal to 1 if the 40-acre units lies within a section given an odd (1, 3, …, 35) number for the first division label within the PLSS demarcation system (MSL 2016, BLM 2016a).

Distance to Stream: The distance to the nearest stream from the centroid of the 40-acre unit given in meters. Calculated in ArcGIS with PLSS data (MSL 2016, BLM 2016a) and stream data (National Atlas 2014) using the near table tool.

Strahler Stream Order: The strahler order of the nearest stream to the 40-acre unit. This information was linked to the near table calculated for the distance to the nearest stream in order to identify the nearest stream's strahler order (National Atlas 2014). Strahler order is discretely measured 1-7 and is based on the number of tributaries that have been combined. When two order 1 streams come together, it becomes an order 2 stream. If another order 1 stream joins the order 2, the joint stream remains order 2. When two order 2 streams combine, it becomes order 3. This process continues through order 7.

Soil Quality: Spatial average of the soil classification within the 40-acre unit. Classification is discrete from 1 (high suitability) to 8 (low suitability) We calculated the spatial average of niccdcd (USDA 2006) for PLSS units (MSL 2016, BLM 2016a) by tabulating the intersection of the layers in ArcGIS.

Elevation (mean): Spatial average of the elevation in meters for the 30 degree grid (USGS 1996) calculated for the 640 acre sections of the PLSS system (MSL 2016, BLM 2016a) using the zonal statistics tool in ArcGIS.

Elevation (st. dev): Spatial standard deviation of the elevation in meters for the 30 degree grid (USGS 1996) calculated for the 640 acre sections of the PLSS system (MSL 2016, BLM 2016a) using the zonal statistics tool in ArcGIS.

Latitude: North-South position of the centroid of the 40-acre unit given in miles calculated in ArcGIS (MSL 2016, BLM 2016a). Note the baseline point for Colorado and Montana are different.

Longitude: East-West position of the centroid of the 40-acre unit given in miles calculated in ArcGIS (MSL 2016, BLM 2016a) Note the baseline point for Colorado and Montana are different.

Additional Variables Referenced:

Fraction Irrigated: The fraction of the 40-acre unit with irrigated land from a surface ditch. Measure is calculated in ArcGIS using shape files from Montana (MTDNRC 2017, MSL 2016) and Colorado (CDSS 2016, BLM 2016a). Fraction came from tabulating the intersections between the respective files.

To the extent that two or more surface ditches serves the same land, our metric overstates the fraction of the unit with irrigation capability. To curtail some over-counting, we truncated the measure at 1.

Patented: An indicator equal to 1 if any part of the 40-acre unit appears in the General Land Office records. Data from BLM (2016b).

Patent Year: Earliest year that a portion of the 40-acre unit was patented conditional on being patented. Data from BLM (2016b).

Railroad Owner: An indicator equal to 1 if the patent authority is the appropriate railroad land grant authorization. In Montana, if authority code is 263004, "Grant-RR Northern Pacific" and in Colorado if authority code is 263003, "Grant-RR Union and Central". If any portion of the 40 acres unit was granted to the railroad, the unit is considered railroad. Data from BLM (2016b)

Reservation[year]: An indicator equal to 1 if the 40 acre-unit (MSL 2016) lies within the boundaries of a Native American Reservation in 1880 or 1915. Reservation shape files for each year were provided by Laura Taylor of the University of Arizona (shared March, 2019). A near table was calculated in ArcGIS and we created an indicator if the distance was equal to zero, indicating the land unit lies within the boundaries. This is only calculated for Montana since the portion of Colorado being analyzed did not contain any reservations.

Development Derailed: Uncertain Property Rights and Asset-Specific Investment

Appendix B: Additional Figures and Tables.

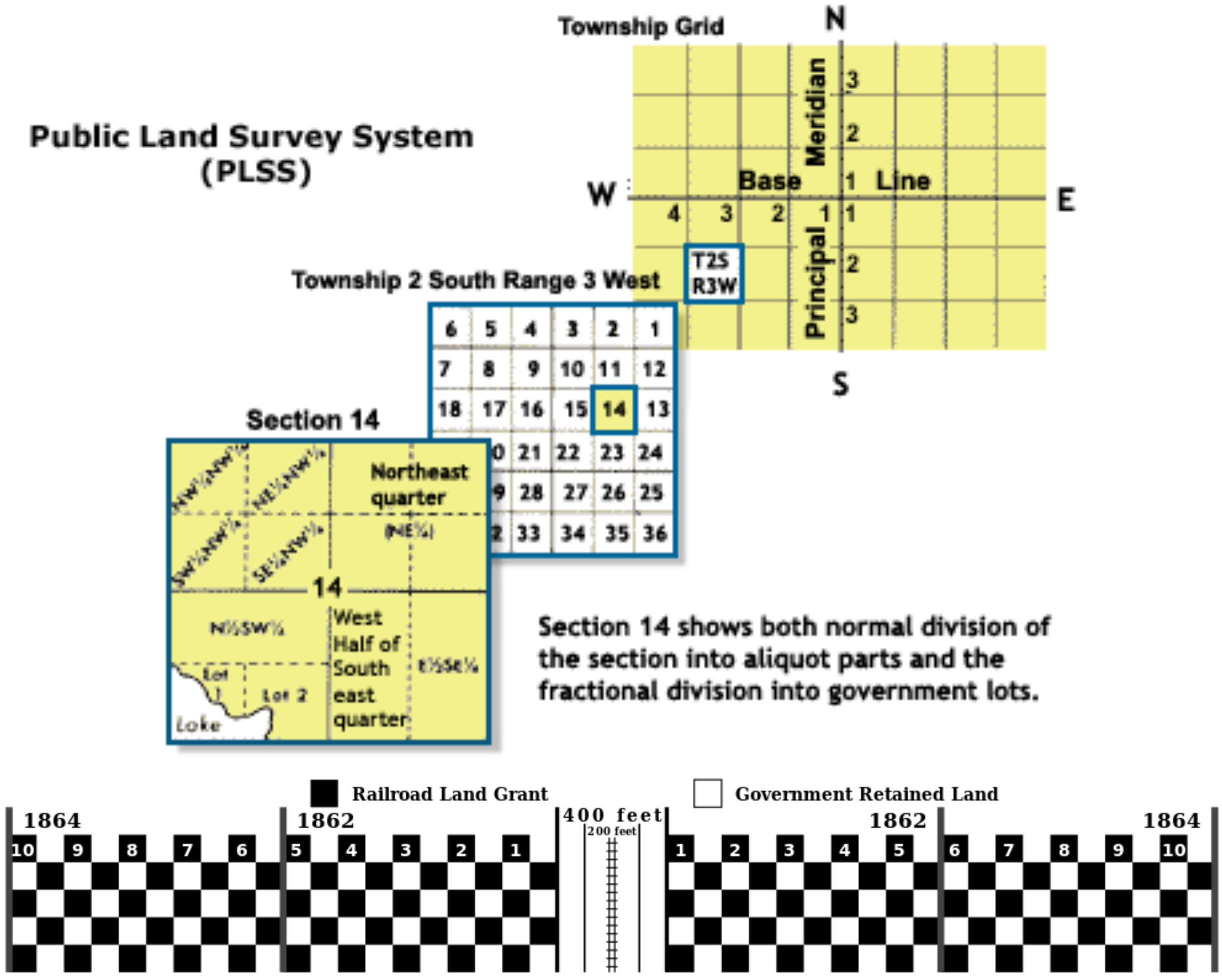


Figure B1: Top: Illustration of the PLSS demarcation system. Source: https://nationalmap.gov/small_scale/a_plss.html Bottom: Illustration of the Railroad Land Grant Checkerboard, both primary and indemnity for the case of the Union Pacific. Source: http://www.wikiwand.com/en/Public_Land_Survey_System

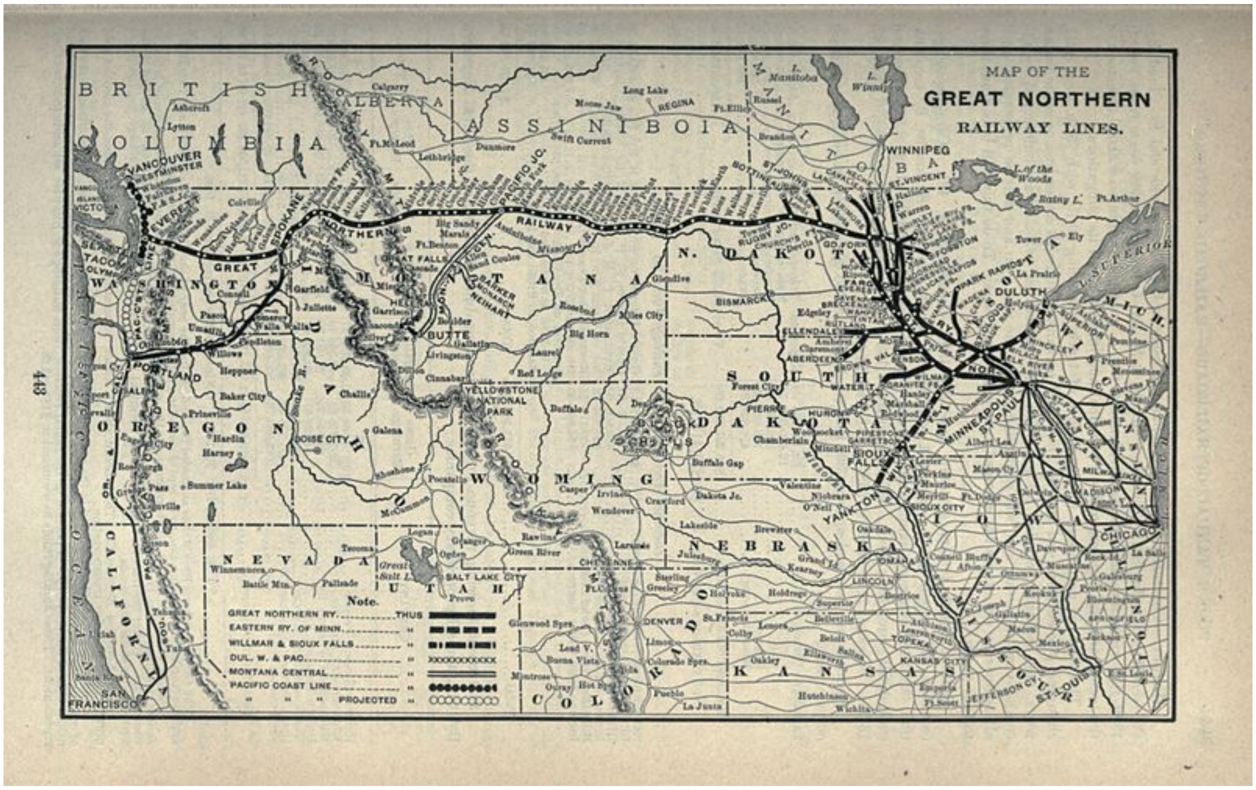


Figure B2: Great Northern Railroad Map, 1897. Source:
https://commons.wikimedia.org/wiki/File:1897_Poor%27s_Great_Northern_Railway.jpg

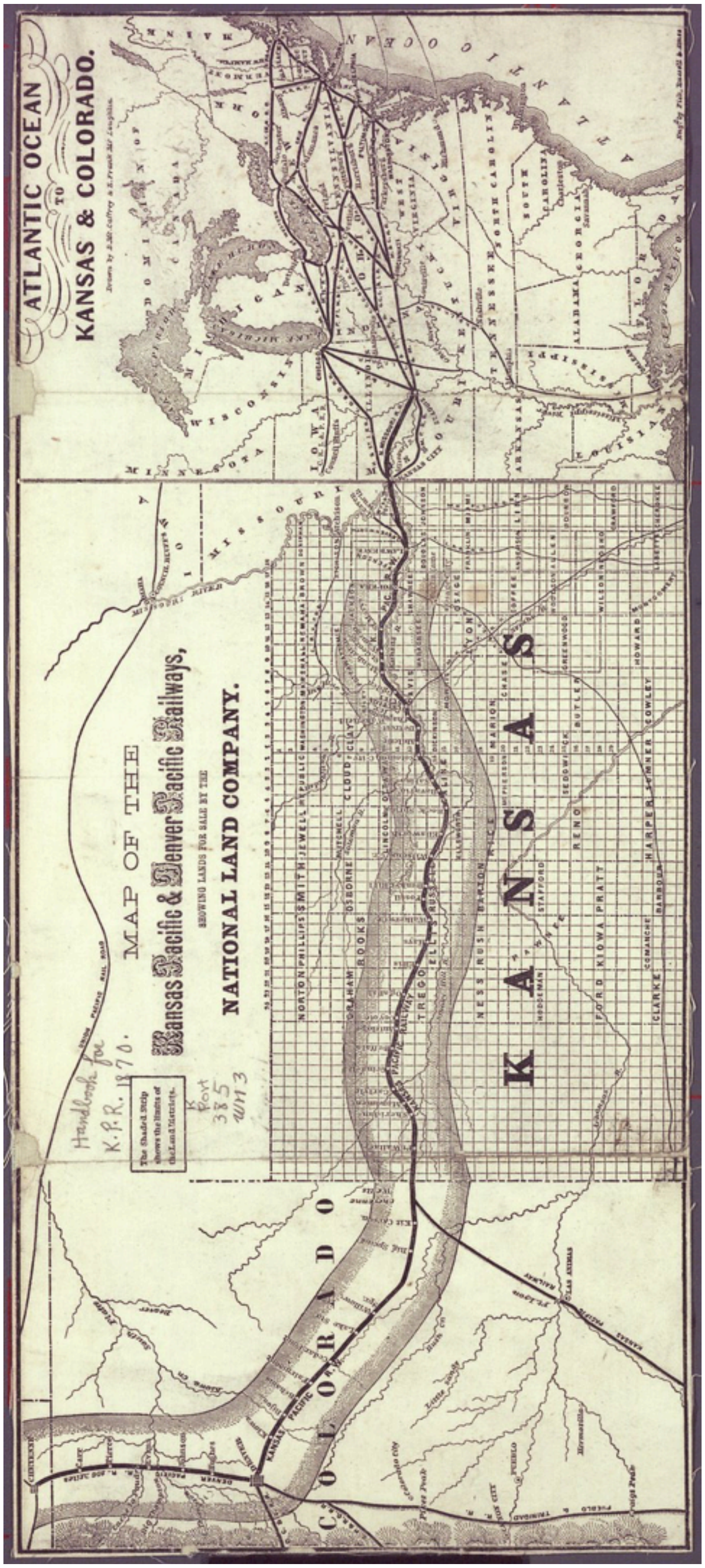
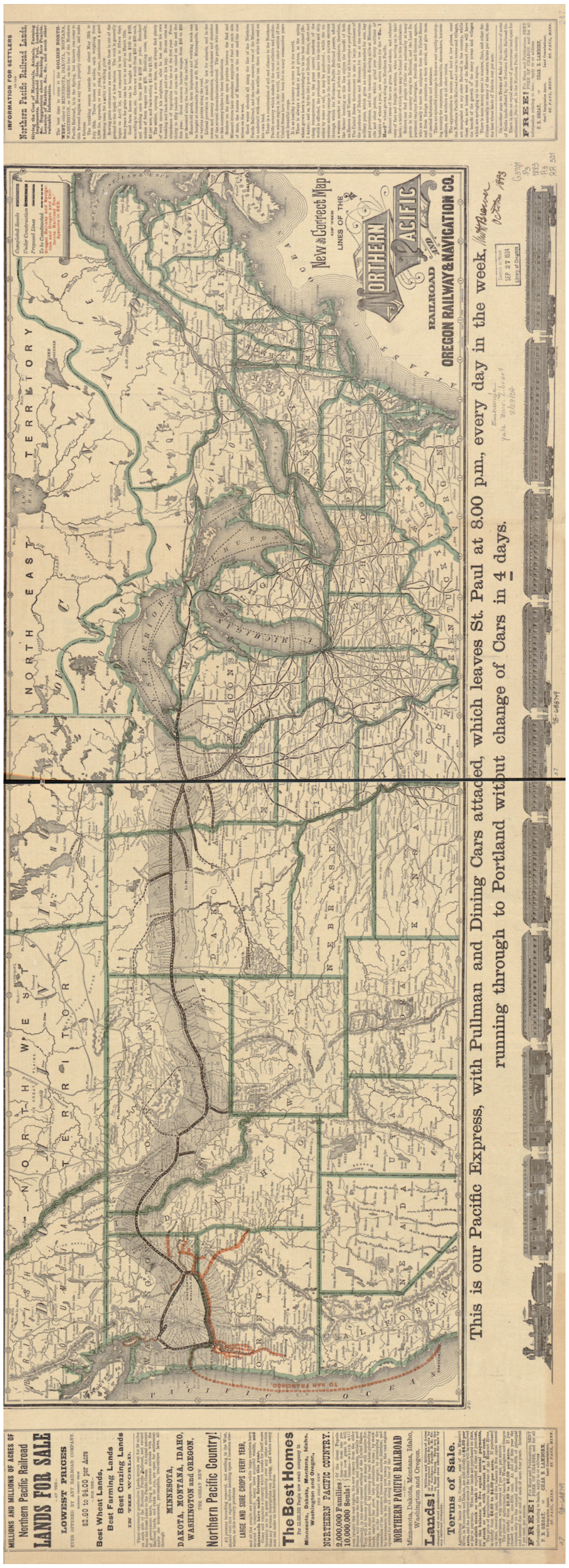


Figure B3: Kansas and Denver Pacific Land Grant Map, 1870. Source: https://www.kshs.org/index.php?url=km/items/view/214193



MILLIONS AND MILLIONS OF ACRES OF

Northern Pacific Railroad

LANDS FOR SALE

—AT THE—

LOWEST PRICES

EVER OFFERED BY ANY RAILROAD COMPANY.

RANGING CHIEFLY FROM

$2.60 to $4.00 per Acre

—FOR THE—

Best Wheat Lands,

Best Farming Lands

Best Grazing Lands

IN THE WORLD.

These extremely productive Lands stretch out for 50 miles on each side of the Northern Pacific Railroad, and extend from the Great Lakes to the Pacific Ocean. An equal amount of government lands, lying in alternate sections with the Railroad lands, and FREE TO ALL, are open for settlement under the homestead, pre-emption, tree-culture laws, all through

Good water abounds all along the line of the Northern Pacific Railroad, and the entire country west of the Missouri is underlaid with coal, the settler can there mine his coal on his own land.

There is a combination of soil and climate in the Northern Pacific country which makes it the most reliable and productive wheat region in the world, and in no other section of the United States have there been for so many consecutive years such bountiful crops.

It is as healthy a country as there is in the world.

Figure B4: Northern Pacific Land Grant Map, 1883. Source: https://www.loc.gov/item/98688749/

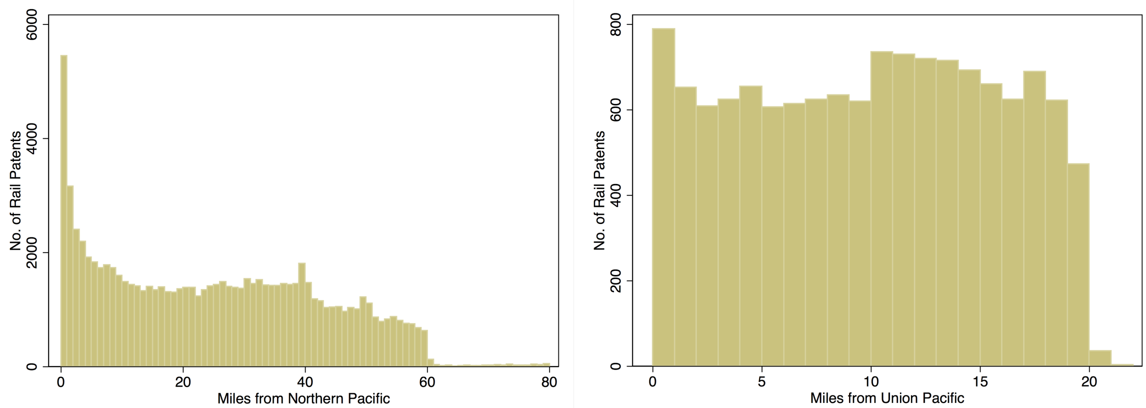


Figure B5: Number of rail patents by distance from the Northern Pacific (left panel) and Kansas Pacific in Colorado (right panel). Tabulated from GLO Data.

Table B1: Northern Pacific Timelines

July 2nd, 1864	Incorporation of Northern Pacific
1870	NP begins construction in MN and WA
May 31, 1870	Additional line authorized in OR and indemnity limits expanded by 10 miles on either side
September 18th, 1873	Cooke & Company bankruptcy
1874 – 1879	Bankruptcy, reorganization and minimal construction
May 24th, 1879	New NP president appointed
July 1, 1879	Completion deadline for land grant
1880	NP reaches Yellowstone River
January 1883	Construction reaches Livingston, MT
September 8th, 1883	Official date of completion with celebration including former President Ulysses S. Grant
1879-1894	Forfeiture efforts
1894	First Montana patent and final legislative forfeiture effort
1941	Indemnity controversy settled

Table B2: Colorado Kansas/Union Pacific Timeline

July 3, 1866	Extension Act authorizes construction west to Denver
May 18, 1868	Construction on Denver Pacific line begins
September 1868	Construction begins in Cheyenne
March 3, 1869	Transfer of Union Pacific Eastern Division Land Grant to Denver Pacific
October 1869	Construction on Kansas Pacific Colorado extension begins
June 22, 1870	Construction on Denver Pacific line completed
August 1870	Construction on Kansas Pacific Colorado extension completed

Note: The table was constructed from several histories of the development of the Kansas Pacific and the Denver Pacific (Noel, 1973; Petrowki, 1974, 1981)[1]

Table B3

Frequency of patents by Entry Class (Statute)

Montana Patents

Entry Class	Freq.	Percent	Cum.
Homestead EntryOriginal	299,866	42.58	42.58
Sale-Cash Entry	103,632	14.71	57.29
Grant-RR Northern Pacific	83,569	11.87	69.16
Homestead Entry-Stock Raising	47,308	6.72	75.88
Indian Trust Patent	32,664	4.64	80.52
Indian Fee Patent	20,750	2.95	83.47
MT-ND-SD-WA Enabling Act	18,442	2.62	86.09
State Grant-School Sec Patent	11,707	1.66	87.75
Indian Homestead Trust	11,414	1.62	89.37
Desert Land Act	11,294	1.6	90.97

Colorado (Water Division 1) Patents

Entry Class	Freq.	Percent	Cum.
Homestead EntryOriginal	64,629	47.46	47.46
Sale-Cash Entry	34,330	25.21	72.67
Grant-RR Union and Central	12,836	9.43	82.1
Colorado Enabling Act	4,775	3.51	85.61
Homestead Entry-Stock Raising	4,222	3.1	88.71
Timber Culture	3,692	2.71	91.42

[1] Noel, Thomas J. “All Hail the Denver Pacific: Denver’s First Railroad.” The Colorado Magazine. L/2. 1973. 91-116.

Petrowski, William R. "Kansas City to Denver to Cheyenne: Pacific Railroad Construction Costs and Profits." *The Business History Review* (1974): 206-224.

Petrowski, William R. *The Kansas Pacific: a study in railroad promotion.* Arno Press, 1981

Table B4

1919 Irrigation Outcomes (w/ Flathead)

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Irrigated (=1)		Priority Year		Failure=Irrigate	
Land Grant Buffer	-0.0161***	0.0207***	4.287***	0.716	-0.0792***	-0.0419
	(0.00180)	(0.00427)	(0.329)	(0.662)	(0.0241)	(0.0593)
Odd Section	0.00110	-0.000411	0.230	-0.00311	0.0191	-0.00699
	(0.00146)	(0.00265)	(0.299)	(0.678)	(0.0245)	(0.0623)
Land Grant Buffer x Odd Section	-0.00526**	0.00159	-0.610	-0.0212	-0.0700**	0.0222
	(0.00223)	(0.00599)	(0.406)	(0.749)	(0.0326)	(0.0754)
Distance to Rail	-0.00166***	-0.0253***	0.211***	0.247**	-0.0144***	-0.309***
	(0.000116)	(0.000590)	(0.0211)	(0.117)	(0.00177)	(0.00884)
Distance to Rail^2	1.71e-05***	0.000617***	4.69e-05	0.0419***	2.50e-05	0.00545***
	(1.85e-06)	(1.71e-05)	(0.000441)	(0.00567)	(3.42e-05)	(0.000369)
Constant	0.495***	0.197*	2.243***	-142.5***		
	(0.00616)	(0.106)	(0.794)	(20.21)		
State	MT	CO	MT	CO	MT	CO
Model	OLS	OLS	OLS	OLS	Hazard	Hazard
Observations	2,124,538	409,960	156,794	37,893	2,124,538	409,960
R-squared	0.080	0.327	0.088	0.614		

Note: Regression Results for PLSS Second Division Land Units (40 Acres). Land Grant Buffer indicates that the unit is within the designated distance from the railroad to be in the land grant area (50 miles for Montana, 20 Miles for Colorado). Odd Section indicates that the unit is contained in an odd section. Railroad distance is in miles from the nearest railroad line (not necessarily the Northern Pacific or Union Pacific). Additional unreported controls include latitude and longitude, distance (and distance squared) to and size of nearest stream, soil quality, and the median and standard deviation of the elevation for the section. Robust standard errors, clustered by section, in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table B5

Robustness for Controls and Models

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Irrigated									
Land Grant Buffer	-0.0216***	-0.0336***	-0.0318***	-0.0211***	-0.0128***	-0.0277***	-0.0467***	-0.215***	-0.264***
	(0.00175)	(0.00182)	(0.00178)	(0.00178)	(0.00143)	(0.00236)	(0.00302)	(0.0262)	(0.0237)
Odd Section	0.00103	0.00101	0.00106	0.00112	0.000860	0.00146	0.000852	0.0211	0.0187
	(0.00149)	(0.00148)	(0.00146)	(0.00146)	(0.00120)	(0.00195)	(0.00256)	(0.0264)	(0.0234)
Land Grant Buffer x Odd Section	-0.00527**	-0.00525**	-0.00523**	-0.00538**	-0.00595***	-0.00740**	-0.00104	-0.0835**	-0.0846***
	(0.00229)	(0.00227)	(0.00223)	(0.00220)	(0.00179)	(0.00296)	(0.00379)	(0.0354)	(0.0315)
Distance to Rail		-0.00283***	-0.00206***	-0.00148***	-0.00144***	-0.00180***	-0.00233***	-0.0122***	-0.0123***
		(0.000120)	(0.000117)	(0.000115)	(9.44e-05)	(0.000155)	(0.000197)	(0.00192)	(0.00169)
Distance to Rail^2		2.63e-05***	1.48e-05***	1.31e-05***	1.54e-05***	1.22e-05***	1.16e-05***	-3.24e-05	-1.14e-05
		(1.87e-06)	(1.84e-06)	(1.82e-06)	(1.48e-06)	(2.54e-06)	(3.21e-06)	(3.65e-05)	(3.13e-05)
Observations	2,133,392	2,133,180	2,133,180	2,120,430	2,120,430	797,205	133,244	2,120,430	2,120,430
R-squared	0.028	0.035	0.063	0.079	0.058	0.092	0.138		
Panel B: Priority Year									
Land Grant Buffer	3.724***	4.770***	4.421***	4.218***	4.576***	4.124***	3.705***		
	(0.335)	(0.330)	(0.329)	(0.330)	(0.409)	(0.306)	(0.271)		
Odd Section	0.249	0.228	0.213	0.228	0.268	0.0970	-0.00146		
	(0.317)	(0.305)	(0.301)	(0.299)	(0.378)	(0.267)	(0.223)		
Land Grant Buffer x Odd Section	-0.661	-0.605	-0.618	-0.604	-0.873*	-0.428	-0.183		
	(0.424)	(0.413)	(0.408)	(0.407)	(0.508)	(0.380)	(0.333)		
Distance to Rail		0.210***	0.244***	0.213***	0.223***	0.185***	0.191***		
		(0.0202)	(0.0214)	(0.0211)	(0.0268)	(0.0199)	(0.0178)		
Distance to Rail^2		0.000119	-0.000448	2.48e-05	-2.42e-05	0.000412	0.000280		
		(0.000430)	(0.000445)	(0.000441)	(0.000567)	(0.000410)	(0.000356)		
Observations	157,037	157,009	157,009	156,794	107,374	84,643	21,959		
R-squared	0.033	0.069	0.082	0.088	0.097	0.086	0.098		
Latitude & Longitude	Y	Y	Y	Y	Y	Y	Y	Y	Y
Railroad Distance	N	Y	Y	Y	Y	Y	Y	Y	Y
Stream Availability	N	N	Y	Y	Y	Y	Y	Y	Y
Farm Suitability	N	N	N	Y	Y	Y	Y	Y	Y
Observations	Main	Main	Main	Main	Small Irrigation=0	Quarter	Section	Main	Main
Model	OLS	OLS	OLS	OLS	OLS	OLS	OLS	Logit	Tobit (Fraction Irrigated)

Note: Regression Results for PLSS Second Division Observations). Panel A's dependent variable is the fraction of a parcel irrigated by 1919. Panel B is the year of irrigation relative to the railroad for observations irrigated by 1919. Land Grant Buffer indicates that the unit is within the designated distance from the railroad to be in the land grant area (50 miles). Odd Section indicates that the unit is contained in an odd section. Various controls, sample restrictions, unit aggregation, and models are tested as indicated. Note that column (4) represents the main specification from the main text. Robust standard errors, clustered by section, in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table B6

Primary and Indemnity Land

	(1)	(2)	(3)
VARIABLES	Irrigated (=1)	Priority Year	Failure=Irrigated
Primary Land Buffer	0.00336	2.903***	0.0825*
	(0.00301)	(0.561)	(0.0488)
Land Grant Buffer	-0.0238***	1.698***	-0.216***
	(0.00293)	(0.578)	(0.0495)
Odd Section	0.00112	0.227	0.0195
	(0.00146)	(0.299)	(0.0246)
Primary Land Buffer x Odd Section	-0.00279	0.229	-0.0275
	(0.00422)	(0.804)	(0.0699)
Land Grant Buffer x Odd Section	-0.00300	-0.796	-0.0492
	(0.00409)	(0.807)	(0.0706)
Distance to Rail	-0.00147***	0.225***	-0.0121***
	(0.000115)	(0.0210)	(0.00180)
Distance to Rail^2	1.31e-05***	0.000116	-2.74e-05
	(1.82e-06)	(0.000436)	(3.45e-05)
Model	OLS	OLS	Hazard
Observations	2,120,430	156,794	2,120,430
R-squared	0.079	0.091	

Note: Regression Results for PLSS Second Division Land Units (40 Acres). Land Grant Buffer indicates that the unit is within the designated distance from the railroad to be in the land grant area (50 miles) and Primary Land Buffer indicates the observation is further within the 40 mile band. Odd Section indicates that the unit is contained in an odd section. Railroad distance is in miles from the nearest railroad line (not necessarily the Northern Pacific). Additional unreported controls include latitude and longitude, distance (and distance squared) to and size of nearest stream, soil quality, and the median and standard deviation of the elevation for the section. Robust standard errors, clustered by section, in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table B7

Railroad Land Grant Effect Relative to the Great Northern

VARIABLES	(1) Irrigated (=1)	(2) Priority Year	(3) Failure=Irrigated
GN/NP Buffer	0.0126***	-8.499***	0.122***
	(0.00279)	(0.497)	(0.0448)
NP Buffer	-0.0288***	11.06***	-0.228***
	(0.00214)	(0.459)	(0.0361)
Odd Section	0.00171	0.254	0.0223
	(0.00246)	(0.432)	(0.0334)
GN/NP Buffer x Odd Section	-0.00102	-0.0583	-0.00627
	(0.00304)	(0.564)	(0.0494)
NP Buffer x Odd Section	-0.00496**	-0.527	-0.0702*
	(0.00243)	(0.455)	(0.0425)
Distance to Rail	-0.00159***	0.275***	-0.0135***
	(0.000117)	(0.0211)	(0.00185)
Distance to Rail^2	1.63e-05***	-0.00153***	5.64e-06
	(1.95e-06)	(0.000445)	(3.65e-05)
Model	OLS	OLS	Hazard
Observations	2,120,430	156,794	2,120,430
R-squared	0.079	0.111	

Note: Regression Results for PLSS Second Division Land Units (40 Acres). GN/NP buffer indicates the observation is within 50 miles of either the Northern Pacific or the Great Northern. NP Buffer indicates it is within 50 miles of the Northern Pacific. Odd Section indicates that the unit is contained in an odd section. Railroad distance is in miles from the nearest railroad line (not necessarily the Northern Pacific or Union Pacific). Additional unreported controls include latitude and longitude, distance (and distance squared) to and size of nearest stream, soil quality, and the median and standard deviation of the elevation for the section. Robust standard errors, clustered by section, in parentheses

Table B8

Montana Irrigation at Various Years

	(1)	(2)	(3)
VARIABLES			
Panel A: Irrigated (=1)			
Land Grant Buffer	-0.00796***	-0.0299***	-0.0205***
	(0.00119)	(0.00205)	(0.00243)
Odd Section	-3.97e-05	0.00172	0.00134
	(0.000964)	(0.00186)	(0.00221)
Land Grant Buffer x Odd Section	-0.000905	-0.00639**	-0.00721**
	(0.00146)	(0.00263)	(0.00313)
Observations	2,120,430	2,120,430	2,120,430
R-Squared	0.048	0.098	0.155
Panel B: Priority Year			
Land Grant Buffer	4.139***	8.342***	13.30***
	(0.290)	(0.384)	(0.538)
Odd Section	0.247	0.104	-0.0583
	(0.248)	(0.281)	(0.482)
Land Grant Buffer x Odd Section	-0.284	-0.115	0.646
	(0.356)	(0.458)	(0.695)
Observations	82,719	231,459	329,740
R-Squared	0.191	0.115	0.077
Year Considered	***1894/1899***	***1941/1946***	***All (2017)***

Note: Regression Results for PLSS Second Division Land Units (40 Acres). Panel A's dependent variable is whether the land is irrigated or not by the first indicated year. Panel B is the year of irrigation relative to the railroad for observations irrigated within 5 years of the cutoff. Land Grant Buffer indicates that the unit is within the designated distance from the railroad to be in the land grant area (50 miles). Odd Section indicates that the unit is contained in an odd section. Railroad distance is in miles from the nearest railroad line (not necessarily the Northern Pacific or Union Pacific). Additional unreported controls include distance (and distance squared) to the nearest railroad, latitude and longitude, distance (and distance squared) to and size of nearest stream, soil quality, and the median and standard deviation of the elevation for the section. Robust standard errors, clustered by section, in parentheses

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

Table B9

Second Division Summary Statistics: Montana within and beyond land grant											
	Beyond					Within					Difference
Variable	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	
Irrigation Development											
Irrigated	1,115,860	0.17	0.37	0	1	1,004,570	0.18	0.38	0	1	-0.01
Irrigated by 1919	1,115,860	0.07	0.25	0	1	1,004,570	0.08	0.28	0	1	-0.02
Water Right Year	174,354	1927.39	32.77	1864	2017	155,386	1923.71	35.98	1859	2017	3.68
Water Right Year by 1919	73,176	1898.22	12.69	1864	1918	83,618	1895.01	13.66	1859	1918	3.21
Patent Data											
Patented	1,115,860	0.37	0.48	0	1	1,004,570	0.28	0.45	0	1	0.09
Patent Year	413,330	1919.93	15.14	1776	1999	283,153	1915.04	18.61	1776	1999	4.89
Controls											
Distance to Railroad (miles)	1,115,860	20.05	16.73	0	74.17	1,004,570	13.70	11.22	0	50.00	6.35
Strahler Stream Order (nearest)	1,115,860	1.63	1.11	1	6	1,004,570	1.62	1.14	1	6	0.00
Distance to Stream (meters)	1,115,860	1673.10	1432.03	0	6262.25	1,004,570	1674.53	1426.66	0	6262.23	-1.42
Soil Quality	1,115,860	4.88	1.74	0	8.01	1,004,570	5.77	1.51	0	8.01	-0.89
Elevation (mean)	1,115,860	1170.85	475.00	573	3570	1,004,570	1274.46	480.08	585	3606	-103.61
Elevation (st. dev.)	1,115,860	23.67	35.48	0	404.58	1,004,570	30.75	41.42	0	363.93	-7.09

Note: Descriptive Statistics for 40 acre PLSS units in Montana differentiated by whether the unit lies within 50 miles of the Northern Pacific. See Appendix A for a full description of the variables.

Table B10

Robustness for Reservation Status						
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES		Irrigated (=1)			Priority Year	
Land Grant Buffer	-0.0172***	-0.0225***	-0.0181***	4.104***	3.466***	3.493***
	(0.00181)	(0.00178)	(0.00181)	(0.321)	(0.305)	(0.303)
Odd Section	0.00112	0.00111	0.00112	0.230	0.210	0.213
	(0.00146)	(0.00146)	(0.00146)	(0.284)	(0.284)	(0.279)
Land Grant Buffer x Odd Section	-0.00538**	-0.00537**	-0.00537**	-0.549	-0.577	-0.553
	(0.00220)	(0.00220)	(0.00220)	(0.397)	(0.389)	(0.386)
Reservation_1880	0.0212***		0.0309***	-4.697***		-2.289***
	(0.00149)		(0.00157)	(0.276)		(0.261)
Reservation_1915		-0.0232***	-0.0416***		-13.16***	-11.73***
		(0.00233)	(0.00246)		(0.551)	(0.568)
Distance to Rail	-0.00151***	-0.00145***	-0.00147***	0.238***	0.246***	0.255***
	(0.000115)	(0.000115)	(0.000115)	(0.0211)	(0.0207)	(0.0208)
Distance to Rail^2	1.66e-05***	1.17e-05***	1.57e-05***	-0.00118***	-0.00157***	-0.00199***
	(1.83e-06)	(1.82e-06)	(1.83e-06)	(0.000443)	(0.000436)	(0.000441)
Observations	2,120,430	2,120,430	2,120,430	156,794	156,794	156,794
R-squared	0.080	0.079	0.081	0.106	0.134	0.138

Note: Regression Results for PLSS Second Division Land Units (40 Acres). Land Grant Buffer indicates that the unit is within the designated distance from the railroad to be in the land grant area (50 miles). Odd Section indicates that the unit is contained in an odd section. Railroad distance is in miles from the nearest railroad line (not necessarily the Northern Pacific). Reservation_YEAR is an indicator whether the unit fell within a reservation boundary in the indicated year. Additional unreported controls include latitude and longitude, distance (and distance squared) to and size of nearest stream, soil quality, and the median and standard deviation of the elevation for the section. Robust standard errors, clustered by section, in parentheses

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

Table B11

Regression Discontinuity: Covariates Irrigation Results, Northern Pacific

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	Strahler	Stream Distance	Soil	Elevation (mean)	Elevation (Std. Dev.)	Irrigated	Priority Year
Discontinuity	0.00764	-31.98	0.0175	-0.362	-0.23	-0.0103***	4.228***
	(0.0154)	(24.85)	(0.0236)	(5.981)	(0.333)	(0.00276)	(0.634)
Observations	1,420,973	1,420,973	1,420,973	1,412,621	1,412,621	1,412,393	113,937
Bandwidth	2.251	2.019	2.448	4.454	8.887	4.867	4.202
Covariates	N	N	N	N	N	Y	Y

Note: Results are for the change in the dependent variable at 50 miles away from the Northern Pacific Railroad. Columns (1)-(5) are the covariates themselves while Columns (6) and (7) are the main dependent variables with covariates included. Estimates come from the rdrobust command in Stata. Observations include only PLSS sections within 80 miles of the Northern Pacific in Montana. Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table B12

Regression Discontinuity: Bandwidth

	(1)	(2)	(3)	(4)	(5)
VARIABLES					
Panel A: Irrigated					
Discontinuity	-0.000742	-0.00786***	-0.00826***	-0.0130***	-0.0109***
	(0.00633)	(0.00273)	(0.00192)	(0.00158)	(0.00138)
Observations	1,420,745	1,420,745	1,420,745	1,420,745	1,420,745
Bandwidth	1	5	10	15	20
Panel B: Priority Year					
Discontinuity	2.031	3.783***	4.868***	3.959***	3.314***
	(1.376)	(0.641)	(0.438)	(0.349)	(0.300)
Observations	114,016	114,016	114,016	114,016	114,016
Bandwidth	1	5	10	15	20

Note: Results are for the change in the dependent variable at 50 miles away from the Northern Pacific Railroad. Estimates come from the rdrobust command in Stata. Observations include only PLSS sections within 80 miles of the Northern Pacific in Montana. Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table B13

Regression Discontinuity: Polynomial Order

	(1)	(2)	(3)
VARIABLES			
Panel A: Irrigated			
Discontinuity (within)	-0.00798**	-0.00811**	-0.00870**
	(0.00334)	(0.00399)	(0.00438)
Observations	1,420,745	1,420,745	1,420,745
Bandwidth	7.268	8.992	11.54
Panel B: Priority Year			
Discontinuity (within)	3.643***	3.926***	1.966**
	(0.786)	(0.905)	(0.866)
Observations	114,016	114,016	114,016
Bandwidth	6.990	8.905	14.98
Polynomial Order	***2***	***3***	***4***

Note: Results are for the change in the dependent variable at 50 miles away from the Northern Pacific Railroad. Estimates come from the rdrobust command in Stata. Observations include only PLSS sections within 80 miles of the Northern Pacific in Montana. Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table B14

Regression Discontinuity: Even Sections

	(1)	(2)
VARIABLES	Irrigated	Priority Year
Discontinuity	-0.0056	4.580***
	(0.00395)	(0.704)
Observations	710,772	57,987
Bandwidth	4.993	8.425

Note: Results are for the change in the dependent variable at 50 miles away from the Northern Pacific Railroad. Estimates come from the rdrobust command in Stata. Observations include only **even** PLSS sections within 80 miles of the Northern Pacific in Montana. Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table B15

Regression Discontinuity: Hazard Model

VARIABLES	(1) Irrigated	(2) Irrigated
Discontinuity (>50 miles)	-0.181	-0.246**
	(0.125)	(0.126)
Miles beyond 50 miles	0.0562*	0.0372
	(0.0322)	(0.0320)
Miles before 50 Miles	0.0153	0.0356
	(0.0448)	(0.0449)
Covariates	No	Yes
Observations	140,552	139,030
Bandwidth	4.814	4.814

Note: Hazard (Cox) regression results for PLSS Second Division Land Units (40 acres). Results are for the change in the dependent variable at 50 miles away from the Northern Pacific Railroad. Estimates come from the stcox command in Stata with irrigated year as the measure of "failure" with development post 1919 treated as survival. Bandwidth selection comes from rdrobust command. Observations include only PLSS sections within 80 miles of the Northern Pacific in Montana. Robust standard errors, clustered by section, in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Development Derailed: Uncertain Property Rights and Asset-Specific Investment

Appendix C: Estimating Costs of Deterred and Delayed Investment

C.1 Impacted Land

In order to calculate the impacted land, we combined observed irrigation rates in 1919 with our estimated coefficients from the main text of equation (1), reported in Table 2, columns (1) and (3).

Deterred Irrigation: We tabulated the number of 40-acre observations contained in even (506,766) and odd (506,039) sections within the 50-mile land grant buffer of the railroad. Multiplying each by the appropriate coefficients, our model suggests 12,824.125 observations in odd sections and 10,684.978 observations in even sections would have been irrigated absent the uncertainty. To arrive at the deterred irrigated acreage, we multiply this total by 40 acres times the average fraction of irrigated 40-acre units covered by irrigation enterprise in 1919 in Montana (0.58), times the share of irrigation enterprises actually irrigated in 1919 (0.38, calculated from Bureau of the Census, 1922, pg. 197, Table 1) or that figure in 1930 (Bureau of the Census, 1932, pg. 142, Table 1). This totals 214,906.65 acres not irrigated in 1920 and 336,457.53 in 1930.

Delayed Irrigation: We tabulate the number of 40-acre observations actually irrigated contained in even (42,969) and odd (40,747) sections within the 50-mile land grant buffer of the railroad. We then scale these counts as we did for deterred irrigation to arrive at 372,485.56 odd acres and 392,797.81 even acres delayed in 1920 and 583,162.85 odd acres and 614,963.66 even acres delayed in 1930.

C.2 1920/1919 Cost Estimates

The principle monetary values for the cost estimate are based on Table 18 of the 1920 Census (Bureaus of the Census, 1922, pg. 206) reporting yields and values for irrigated crop land for each crop along with comparisons for non-irrigated land in Montana. We provide an image of this table in Figure C1. For each crop, we calculate the implied per unit value on irrigated land. While irrigated crops may fetch a higher value due to better quality, we apply the same market price to non-irrigated crops due to data limitations but note this will lead us to understate the irrigation premium. Then for each crop, we calculate the additional monetary value of crops grown per acre on irrigated land over non-irrigated land. Finally, we calculate an area-weighted average given the observed number of irrigated acres in each crop. This comes to $13.81 (1919 prices). If the comparison is to no farming rather than non-irrigated, the irrigated crop revenues average $34.73 per acre (1919 prices).

	Crop.	Average yield per acre, 1919.						Value.				
					On irrigated land.			1919		1909		
		Unit.	For state.	On non-irrigated land.	Average.	Per cent of average for state.	Per cent of average on non-irrigated land.	Amount.	Per cent of total for state.	Amount.	Per cent of total for state.	Per cent of increase.[1]
	Cereals:											
1	Corn	Bu.	8.5	7.7	14.0	164.7	181.8	$58,024	21.4	$38,613	20.8	50.3
2	Oats	Bu.	13.5	9.6	26.2	194.1	272.9	1,183,068	45.8	3,273,203	53.2	—63.9
3	Winter wheat	Bu.	5.2	4.9	8.4	161.5	171.4	792,687	11.9	} 1,064,794	20.0	322.7
4	Spring wheat	Bu.	4.3	3.3	12.7	295.3	384.8	3,708,527	31.0			
5	Barley	Bu.	11.8	8.5	18.1	153.4	212.9	278,799	53.6	189,952	39.7	46.8
6	Rye	Bu.	3.0	3.0	5.0	166.7	166.7	11,263	3.0	10,985	13.3	2.5
	Hay and forage:											
7	Timothy alone	Tons.	0.78	0.60	1.00	128.2	166.7	1,050,584	56.8	736,041	46.2	42.7
8	Timothy and clover mixed	Tons.	1.07	0.91	1.15	107.5	126.4	3,175,350	70.4	952,118	65.3	233.5
9	Clover alone	Tons.	1.04	0.88	1.25	120.2	142.0	205,526	51.0	126,659	71.8	62.3
10	Alfalfa	Tons.	1.57	1.15	1.86	118.5	161.7	11,247,308	69.7	3,188,918	84.1	252.7
11	Other tame grasses	Tons.	0.85	0.68	1.01	118.8	148.5	1,047,360	61.6	318,494	55.0	228.8
12	Annual legumes cut for hay	Tons.	0.73	0.62	1.54	211.0	248.4	28,416	25.4	} 81,597	13.8	470.0
13	Small grains cut for hay	Tons.	0.37	0.35	0.72	194.6	205.7	436,656	10.6			
14	Wild, salt, or prairie grasses	Tons.	0.62	0.55	0.74	119.4	134.5	3,093,822	46.8	2,392,486	57.9	29.3
15	Silage crops	Tons.	4.05	3.40	5.41	183.6	159.1	40,284	43.2	(2)	....	....
	Vegetables:											
16	Potatoes	Bu.	74.8	63.2	115.8	154.8	183.2	1,334,819	34.2	755,968	58.2	76.9
	Fruits:											
17	Apples	Bu.	[5]0.6	[5]0.7	[5]0.6	100.0	85.7	788,363	70.9	(2)	....	....
18	Cherries	Bu.	[5]0.2	[5]0.3	[5]0.2	100.0	66.7	39,819	65.0	(2)	....	....
	Miscellaneous:											
19	Sugar beets grown for sugar	Tons.	8.58	7.14	8.76	102.1	122.7	740,267	91.2	461,208	84.9	60.5
20	Clover and alfalfa seed[4]	Bu.	2.4	2.3	2.6	108.3	113.0	211,776	37.8	36,007	40.7	488.2
21	Dry beans	Bu.	11.4	9.1	14.3	125.4	157.1	61,219	55.8	(2)	....	....
22	Dry peas	Bu.	11.2	8.4	11.9	106.2	141.7	443,430	85.9	31,824	84.3	....
23	Flaxseed	Bu.	2.5	2.4	6.0	240.0	250.0	100,276	6.9	(2)	....	....
24	Sugar-beet seed	Lbs.	571.1	628.2	526.8	92.2	83.9	305,031	52.0	(2)	....	....

[1] A minus sign (—) denotes decrease. Per cent not shown when more than 1,000.
[2] Not reported separately in 1910.
[3] Number of trees of bearing age.
[4] Not including red clover seed.
[5] Yield per tree.

Figure C1: Image of the bottom portion of Table 18, 1920 Irrigation Census for Montana (Bureau of the Census 1922, pg. 206)

These revenues are offset by the costs of irrigation. From table 10 (Bureau of the Census 1922, pg. 202) we find that maintenance costs of irrigation systems in Montana average $1.26 per actual irrigated acre in 1919. Furthermore, in the same table, it is reported that irrigation capital costs through 1920 were $18.94 per irrigated acre in Montana. To find the losses for deterred irrigation, we take the irrigated crop revenue gains and subtract off the annual maintenance costs. With this net gain of irrigation, we calculate the net present value for this additional income flow into the infinite future using Fogel's social discount rate of 0.0791 (Fogel 1962). Though sensitive to this choice, we picked it to align with recent work done on the gains of the prior appropriation doctrine over the riparian doctrine by Leonard and Libecap (2019) which allows for some comparison to their numbers as well. Finally, from this net present value, we subtract off the capital costs. The implied gain in net present value of irrigation over no crops is $437.66 per acre while the net gain over non-irrigated crops is $152.27 per acre.

For delayed irrigation we calculate the net present value loss of the first 4.21 years on even sections and 3.84 years on odd sections (based on estimated coefficients of delay) of the additional crop revenue minus the maintenance costs. We then add back in the net present value of gain of delaying the capital investment by the same number of years.

For comparisons to total farm value in Montana, we use the state total $776,767,529 (1920 value) from Haines (2010). We then adjust values to 2015 $ using CPI (BLS 2019).

C.3 1930 Cost Estimates

The principle monetary values for the cost estimate are based on 1930 census data. The intuition is that farms, both irrigated and non-irrigated, were more valuable in 1930 within the land grant buffer then beyond. This is demonstrated with a binary regression for the county irrigated farm value per irrigated farm acre on the fraction of the county within the land grant buffer. We then do the same for non-irrigated farms (full variable descriptions are provided at the end). Results are provided in Table C1.

Table C1: 1930 Irrigation Value Regression Results

Average Irrigated and non-irrigated land value, 1930 Montana

	(1)	(2)	(3)	(4)
	Irrigated Farm Value		Non-Irrigated Farm Value	
VARIABLES	Level	Logged	Level	Logged
Fraction NP Grant	7.460**	0.411**	0.196	0.0558
	(3.678)	(0.187)	(2.139)	(0.166)
Constant	12.43***	2.390***	12.04***	2.339***
	(2.618)	(0.133)	(1.523)	(0.118)
Observations	51	51	51	51
R-squared	0.077	0.090	0.000	0.002

Note: Binary regressions for Montana Counties, 1930. Dependent variables are the per acre value for irrigated farms (level and logged) and the per acre value for non-irrigated farms (level and logged). The independent variable (Fraction NP Grant) is the portion of the county contained in the 50 mile buffer surrounding the Northern Pacific. Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

However, for the values underpinning our cost calculations, we draw upon the averages of the 14 counties completely within the buffer and the 14 counties completely beyond the buffer. Average per acre farm values on irrigated farms in 1930 for counties within the buffer was $22.14 and $11.56 for counties beyond the buffer (1930 prices). For non-irrigated farms the values were $13.66 and $12.01 respectively. We then combine these to conduct counterfactuals for various outcomes as displayed in Table C2:

Table C2: 1930 Counterfactual Calculations

	Losses per Irrigated Farm Acre (1930 $'s)	
Counterfactual	**No Investment**	**Displaced Investment**
No Crops	$22.14	$22.14-$11.56=$10.58
Dry-land crops	$22.14-$13.66=$8.48	($22.14-$11.56)-($13.66-$12.01)=$8.93

Note: $22.14 is the average irrigated farm value per acre for counties entirely within the NP land grant. $13.66 is the average non-irrigated value within the land grant. $11.56 is the average irrigated value for counties entirely beyond the land grant and $12.01 is the average value for non-irrigated farms beyond the land grant.

We then combine these values with the extent of land impacted. Because these values are per farm acre, we further take our irrigated acreage calculations from above and divide them by the average irrigated acres per irrigated farm in 1930 in Montana to find the implicated number of farm acres (1,594,912/12,032,619=0.1325 [Census of the Bureau 1932, pg. 142, Tables 1 and 2]). To find the reduced value for deterred acres, we simply multiply land impacted by the values shown in Table C2.

For delayed acreage, we first find the implied annualized losses of the difference reported in Table C2 amount using the 0.0791 social discount rate. We then calculate the net present value of this annual amount for the implied odd sections for 3.84 years and even sections for 4.21. We only conduct this delay estimate for the "no investment" case. It did not seem reasonable to assume the delayed irrigation was in fact initially irrigated beyond the land grant buffer only for that irrigation to cease and commence, abandoning the infrastructure in order to build new infrastructure, within the land grant.

The scaling for total farm value in Montana is based on a value of $527,610,002 (1930 values) which can be found, among other places, in Table 2 of the 1930 Montana Irrigation Census report (Bureau of the Census 1932, pg. 142). Values are then adjusted by the 1930 CPI (BLS 2019) to 2015 dollars.

C.4 Variable Description

Irrigated
Farm Value: Calculated from Haines (2010) digitization of the census, 1930_2 file. The variable takes the total value of land and buildings for irrigated farms (VAR1553) and divides that by the total number of acres contained in irrigated farms (VAR1509). The variables are measured at the county level.

Non-Irrigated
Farm Value: Calculated from Haines (2010) digitization of the census, 1930_2 file. The variable is calculated similar to irrigated farm values but requires first calculating the non-irrigated numerator and denominator. For total value of land and buildings in non-irrigated farms, we subtract the value for irrigated farms (VAR1553) from the total farm value (VAR1552). For total land in non-irrigated farms, we subtract land in irrigated farms (VAR1509) from the total farm acres (VAR1508).

Fraction NP Grant: Calculated in ArcGIS. First, a 50-mile buffer is constructed around the Northern Pacific rail line (ESRI 2016) and then we tabulated the intersection of this buffer with the 1930 county shapes (Minnesota Population Center 2011).

C.5 Data Sources:

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