IRRIGATION INVESTMENT ON AN AMERICAN INDIAN RESERVATION

MUYANG GE, ERIC C. EDWARDS, AND SHERZOD B. AKHUNDJANOV

American Indian reservations have low incomes and high rates of poverty relative to adjacent communities, and the income gap appears to be even larger for Indian farmers. We examine the extent to which a lack of access to capital might explain these differences using irrigation systems as a proxy for on-farm investment around the Uintah-Ouray Indian Reservation in eastern Utah. Uintah land is held in trust by the US government, and farmers on this land face significant barriers to acquiring capital to invest in irrigation equipment and infrastructure. We use the boundaries from a 1905 land allotment as a natural experiment, employing both sharp and fuzzy regression discontinuity designs to explore whether agricultural land use, irrigation levels, irrigation investment, and crop choice differ across the boundary. The original allocation provided similar land in the immediate neighborhood around its borders, and our results suggest that today tribal trust land is farmed and irrigated at rates similar to adjacent land. However, conditional on being irrigated, tribal trust land is around thirty-two percentage points less likely to utilize capital-intensive sprinkler irrigation, and up to ten percentage points less likely to grow high-value crops. Trust ownership, which is characterized by cumbersome bureaucratic processes, limits on agricultural lease flexibility, and the inability to use land as collateral to acquire loans, is a likely explanation for the observed differences.

Key words: Indian reservation, irrigated agriculture, property rights, regression discontinuity.

JEL codes: Q15, Q24, Q25.

The median household income for American Indian and Alaskan Native communities in the United States is around 30% lower than the national average, and this divergence is even more pronounced in terms of agricultural income.[1] In 2007, average sales on a farm whose operator identified as American Indian or Alaskan Native, often on a reservation, were $40,331, less than 1/3 of the equivalent US average (U.S. Department of Agriculture 2007). On average, American Indian farms are substantially larger and more likely to be engaged in ranching than US farms generally, characteristics often associated with less productive or more arid land. However, unlike elsewhere in the United States, observed land quality on American Indian reservations is not always associated with higher incomes, suggesting reservation land policies and allocation rules may inhibit production (Leonard, Parker, and Anderson 2020). The link between restrictive institutions governing land use and high levels of poverty on American Indian reservations has drawn significant attention in recent years (Anderson and Lueck 1992; Cornell and Kalt 2000; Anderson and Parker 2008; Anderson and Parker 2009; Russ and Stratmann 2016). Although these studies typically look at outcome variables like agricultural output, per capita income, or land value, there has been limited research examining the

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[1] U.S. Census Bureau, 2012–2016 American Community Survey Five-Year Estimates.

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direct effect on capital investment in general (see Akee and Jorgensen 2014) or, specifically, in agriculture. With 75% of land in Indian country dedicated to agriculture, understanding the productivity of tribal land is key to improving economic development (Shoemaker 2006).

In this paper, we use the empirical case of the Uintah and Ouray (Uintah) Reservation in the state of Utah to understand how land tenure affects farm-level outcomes: land in agriculture, irrigated land, irrigation type, and crop type. The Uintah Reservation is the second largest by area in the United States, and there are primarily two land tenure types within the reservation boundary: fee-simple ownership, which provides secure title and allows the landowner to freely sell or lease the land; and tribal trust, which is land owned by the US government in trust for the tribe and has sale, lease, and use restrictions. In 1905, the tribe was allotted a few contiguous blocks of land from within the reservation boundary, with the remaining portions of the reservation opened to white settlement, while technically remaining within the reservation boundary. Within the allocation, some land became fee simple, but portions of the original allocation reverted to tribal trust. On trust lands, a lack of access to commercial credit can limit the opportunity to borrow money for capital-intensive improvements through at least three channels: inability of lenders to enforce contracts on reservations (Anderson and Lueck 1992), short and restrictive lease terms (Shoemaker 2006), and bureaucratic delay (ILTF 2003).

We use irrigation systems as a proxy for on-farm investment. Traditional gravity, or flood, irrigation systems require a relatively low up-front investment but are limited in how precisely they apply water and are less efficient in general. Sprinkler systems, in contrast, require significant upfront investment, up to $1,000/acre or more, but provide gains on the intensive margin (higher yields for the current crop) and extensive margin (switching to a higher value crop). We develop a new dataset by linking agricultural variables, current land ownership, and historic land allocation to compare fee-simple and tribal trust lands in the neighborhood of the 1905 allotment boundary using a spatial regression discontinuity (RD) design. A similar empirical strategy has been widely applied in the literature to identify the effect of a variety of institutional settings (see, for instance, Bayer, Ferreira, and McMillan 2007; Dell 2010; Grout, Jaeger, and Plantinga 2011; Dachis, Duranton, and Turner 2011; Dell 2015; Card and Giuliano 2016; Pan, Smith, and Sulaiman 2018).

Because the location of the 1905 boundary line relative to land in the immediate vicinity is plausibly exogenous to current irrigable land suitability, we first implement a sharp RD design across the boundary. Given that some land within the allotment area has been converted to fee simple, while some land outside has reverted to tribal control, our sharp RD design focuses only on the remaining lands, which are the same type today as they were in 1905. This approach requires that the land that has remained in fee simple ownership be similar across the boundary to land that has remained under tribal control. Although this condition is generally met across the boundary for observable variables, we still worry selection into treatment might be dependent on unobservable factors. As a result, our second empirical strategy utilizes all parcels and applies a fuzzy RD design by treating the 1905 boundary as an instrument for current land ownership and rescales the observed effect of the discontinuity based on the probability of receiving treatment using a nonparametric local linear (polynomial) estimator.

Results are generally consistent across both specifications. The 1905 land allotment provided nearly identical land in the immediate neighborhood around its border in terms of agricultural production potential, climate, and elevation, although trust land does appear to have been located closer to rivers and is slightly drier. Today, trust land is just as likely or more likely to be farmed and just as likely to be irrigated as adjacent fee-simple land. However, conditional on being irrigated, trust lands see significantly less investment in capital-intensive irrigation systems: up to thirty-two percentage point lower rates of sprinkler irrigation using the fuzzy RD design and up to twenty-two percentage points lower using the sharp RD design. Trust land also sees a four to ten percentage point lower rate of high value crops on all agricultural lands under the fuzzy RD design, and a three to ten percentage point lower rate under the sharp RD design.

Our findings suggest that land held in tribal trust lags in agricultural production and irrigation investment. Although there is significant evidence that the divergence is related to tribal trust land ownership, other channels, discussed later in the paper, may also play a role. The paper proceeds as follows.

Section 2 provides background on tribal trust and investment along with motivating economic theory; section 3 presents background information on the Uintah Reservation. Section 4 describes the data construction and section 5 provides details on the empirical design and econometric approach. Results are provided in section 6 and section 7 concludes.

Tribal Trust and Investment

Reservation allocations were initially made to tribes collectively, but as land pressure increased, the US Congress passed the Dawes Act (1887), which tasked agents representing the Bureau of Indian Affairs (BIA) with reserving land for allotment to tribal members and opening the remaining land for white settlement (Carlson 1981; Leonard, Parker, and Anderson 2020). In the allotted areas, tribal members could claim parcels for individual ownership. The Indian Reorganization Act (1934) again changed the rules, and all unclaimed allotment land reverted to tribal control. The result today is a patchwork across Indian country of three categories of land ownership: fee simple, land which is privately owned; tribal trust, land owned by the federal government in trust for the tribe; and individual trust, land owned by the federal government in trust for individuals. The Uintah Reservation has virtually no individual trust land, and thus for the remainder of the paper we concentrate on tribal trust land relative to fee simple.

Tribal trust land is managed jointly by tribal governmental organizations and the BIA. The BIA maintains ownership records and manages almost every transaction involving trust land. Trust property cannot be transferred, alienated, or leased without the approval of the BIA. These approvals typically require long appraisal and documentation processes. In 2003, the Indian Land Tenure Foundation (ILTF) conducted a community survey to understand tribal members' views on land ownership and management. It found perceptions of systematic barriers in the use of property rights related to land and natural resources, especially the slowness of BIA actions. Specifically, that the federal bureaucracy is unable to provide legal certainty or act quickly and is insensitive to traditional ways and knowledge (ILTF 2003). Anderson and Lueck (1992) show that trust land constraints imposed by the federal government significantly reduced the value of agricultural output on reservation land.

Many private commercial lending difficulties exist on trust lands. Individuals seldom own direct title and therefore do not have collateral. It is nearly impossible to get title insurance on tribal trust land because only a few title insurance companies are qualified to offer it. Loans secured by trust land still require BIA approval, and there is no uniform approval process for different BIA offices.[2] For Indian farmers and ranchers, trust land creates jurisdictional uncertainty that reduces access to credit. Even though tribes function as sovereign entities, according to their governing bylaws, the U.S. Secretary of Interior has final authority over many tribal actions. For instance, agricultural leases may be negotiated directly with the tribal government, but they are still subject to BIA approval. Tribal leases are subject to the National Environmental Policy Act, which applies to federal agencies but not private fee-simple sales or leases (Shoemaker 2006). Leases are codified as having a maximum duration of ten years, unless substantial investment is required, in which case twenty-five year leases are possible (25 U.S.C. § 3715(a)(1)).

Previous research on property rights and investment suggests multiple channels through which land property rights affect agricultural investment (Demsetz 1967; Besley 1995; Anderson and Parker 2008). We provide a simple, illustrative model in which x measures the security of a property right to land (Feder 1988; Besley 1995). A farmer who invests capital, k, in his farm earns a return, $I(k, x)$, which is increasing and concave in k. The first order condition for optimal investment is $I_1(k,\ x) = 0$. Taking the total derivative leads to $\frac{\partial k}{\partial x} = -\frac{I_{12}(k,x)}{I_{11}(k,x)}$. Because of the concavity of the investment function, the maximum point exists if $I_{11} < 0$. Importantly, if $I_{12} > 0$ then $\frac{\partial k}{\partial x} > 0$, and there exists a positive relationship between agricultural investment and property right security.

Suppose a farmer would like to borrow money, b, from a lender to invest in a sprinkler system. The lender charges an interest rate of r (x). The interest rate offered by a lender is

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[2] Information is summarized from U.S. Department of Treasury (2006) *Guide to Mortgage Lending in Indian Country*.

decreasing in property right security, $\frac{\partial r(x)}{\partial x} < 0$. Stated differently, the interest rate is increasing in the inability to use land as collateral, shorter investment time-horizons, and longer administrative approval processes. The physical return from the new sprinkler system is $R_p(k)$, where $R_p'(\cdot) > 0$ and $R_p''(\cdot) < 0$, and the probability of earning the return is q. The utility function $u(\cdot)$ is a smooth, concave, and increasing function. Thus, the farmer's expected utility is:

$$(1) \quad I(k,x) = \max_{\{b,k\}} \{u(b-k) + q \cdot u(R_p(k) - r(x) \cdot b) + (1-q) \cdot 0\}$$

The first order conditions with respect to the choice variables $\{b, k\}$ can be specified. Solving the first-order conditions for equation 1, it is straightforward to show that:

$$(2) \quad R_p'(k) = r(x)$$

In words, the marginal productivity of capital invested in a farm is equal to the interest rate charged by a lender. The first order condition for the choice of k, after the envelope theorem is used for the choice of b, can be written as:

$$(3) \quad I_1(k,x) = R_p'(k) - r(x)$$

Taking the derivative with respect to x:

$$(4) \quad I_{12}(k,x) = -\frac{\partial r(x)}{\partial x}$$

Because we assume a negative relationship between land property rights and interest rate, $\frac{\partial r(x)}{\partial x} < 0$, we can conclude that $I_{12}(c,\ x) > 0$. Because the interest rate is equal to the required marginal productivity of capital investment, the result shows that lower interest rates increase investment (Feder and Feeny 1991; Besley 1995).

A higher cost of capital as a result of insufficient collateral, short lease durations, and/or uncertain approval processes suppresses agricultural investment. In the empirical analysis, we focus on whether this prediction holds for investment in irrigation capital. Capital is required to construct irrigation works; to purchase pumps, pipes, and other equipment; to prepare a field to receive water; and to maintain and improve existing systems. Both flood and sprinkler irrigation require capital expenditures, although the investment cost of flood irrigation is significantly lower than sprinkler systems, such as center pivot systems (Dumler, Rogers, and O'Brien 2007). Importantly, a more-efficient sprinkler system increases crop yield and allows for more acres to be irrigated (Dumler, Rogers, and O'Brien 2007). Further, irrigation, and particularly sprinkler irrigation, increases a farmer's ability to grow high-value crops. Therefore, on two otherwise identical parcels, we expect: (*a*) conditional on irrigation, less investment in sprinkler irrigation on trust land; and (*b*) lower value crops to be grown on trust land.

The Uintah and Ouray Reservation

The Uintah and Ouray Reservation was established for the native people of eastern Utah as a combined reservation in 1886 (Duncan 2000, p.196). The passage of the Dawes Act in 1887 and subsequent 1898 act by Congress specifically about the Uintah Reservation started the process of setting aside land for individual tribal members, the allotment, and opening the remainder of the reservation for white settlement.[3] The Utah Congressional delegation, led by Rep. George Sutherland, pushed hard for the immediate opening of prime lands for white settlement (O'Neil and MacKay 1979; Conetah 1982, p.125). Indian agents working for the BIA strove to make an acceptable allotment that included viable agricultural lands. However, information on the character of the lands being allotted was low, with the Indian agents complaining of inadequate field data to determine whether soil was suitable for agriculture. The Ute People adamantly opposed allotment.[4] A commission of three agents was appointed on April 3, 1905, and had created and finalized allotment boundaries within two months, without tribal input. These allotments were subsequently approved

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[3] Originally, the Ouray reservation was established for the Uncompahgre Band, but when it was determined the land on the reservation was not suitable for agriculture, they were grouped with the Uintah Band and White River Band for allotment on what had originally been labeled the Uintah Reservation.

[4] As planning proceeded, James McLaughlin, a US Indian inspector, met with tribal members in 1903 and suggested the tribe would be allowed to choose their allotment if they agreed to participate in the process; all 127 Ute men present at the meeting refused (Barton and Barton 2001). Although a few dubious agreements were eventually made with some tribal members, the land allotment by and large occurred without the participation of the Ute People (Conetah 1982, p.126).

by Congress in July and the non-allotted reservation lands were opened for settlement on August 28, 1905, leading to a land rush by white settlers. A similar lack of information encompassed this endeavor, and many of the settler homesteads failed due to poor soil and a lack of water (Conetah 1982, p.126).

Figure 1 provides an overview of the reservation and the allotment boundaries. The Indian agents appear to have tried to balance their competing objectives, assigning tribal allotment lands near water for irrigation but doing so quickly without much information. The importance of the apparent exogeneity of the exact boundary lines to our statistical identification strategy is discussed below.

Under the allotment policy, adult members of the Uintah tribe could claim between 40 and 640 acres, depending on the suitability of the land for farming. This property was held in protected status that forbade it being sold by the individual for twenty-five years, at the end of which time the owner would be recognized as an American citizen (McPherson 2000, p.22). In 1906, the federal government authorized construction of the Uintah Indian Irrigation Project, which provided water to 80,000 acres, including the majority of allotment lands as well as non-allotment areas (O'Neil and MacKay 1979). However, a provision in the act allowed the tribe to sell land once it was fit for agricultural production. Within fifteen years of the allotment, tribal members had sold or leased 30,000 acres of Uintah land, much of which was then irrigated by non-Indian farmers (Duncan 2000, p.207), leading to the divergence between land ownership today and the allotment boundary as seen in figure 1.

In 1937, under the 1934 Indian Reorganization Act, all tribal lands that had not been privatized reverted to Uintah control. The tribe was able to add additional acreage over time through purchases and legal actions, but tribal agriculture was primarily concentrated around the original allotment areas, which represented the best agricultural land. Figure 2 shows current land ownership relative to the allotment boundaries. Federal lands located around the northern and western boundaries of the Uintah and Ouray Indian reservation are primarily national forest in the Uintah Mountains. Tribal land is held in trust and the U.S. Secretary of the Interior must approve many Uintah tribal actions, which hinders the tribe's ability to create economic growth (Duncan 2000, p. 222). Even though the Ute Tribe is one of the major economic

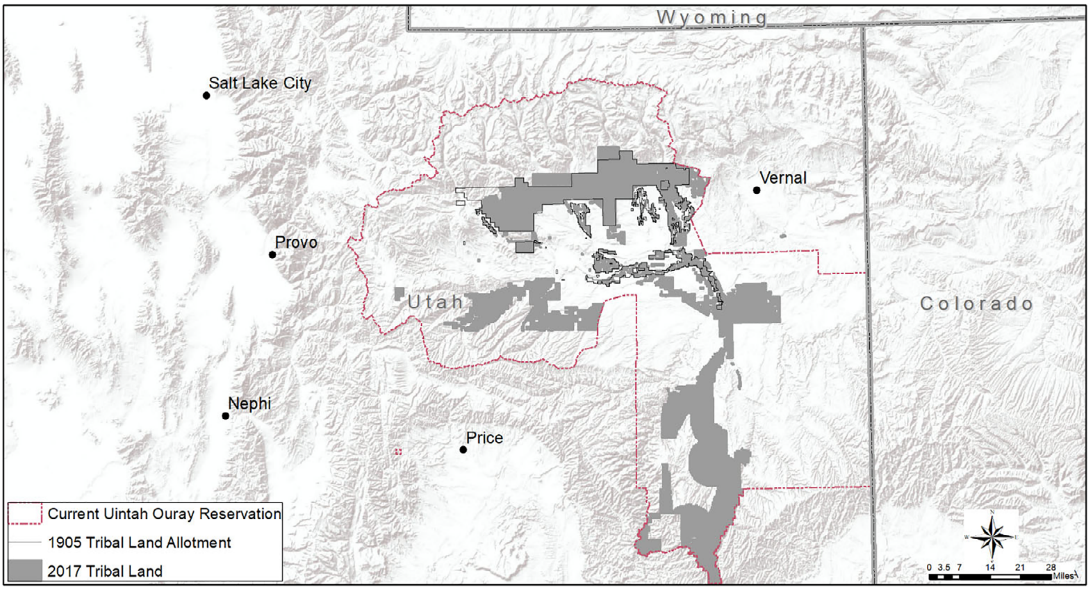

Figure 1. Overview of the Uintah-Ouray reservation

Notes: The 1905 allotment is digitized from the Uintah Indian Reservation Disposition Map. The Uintah-Ouray reservation boundary designates the area under which the tribal government has some jurisdiction, but not all the land is held by the tribe; within the reservation boundary there is fee-simple, federal, state, and tribal trust land.

Source: Author's map created with data from the State of Utah and ESRI.

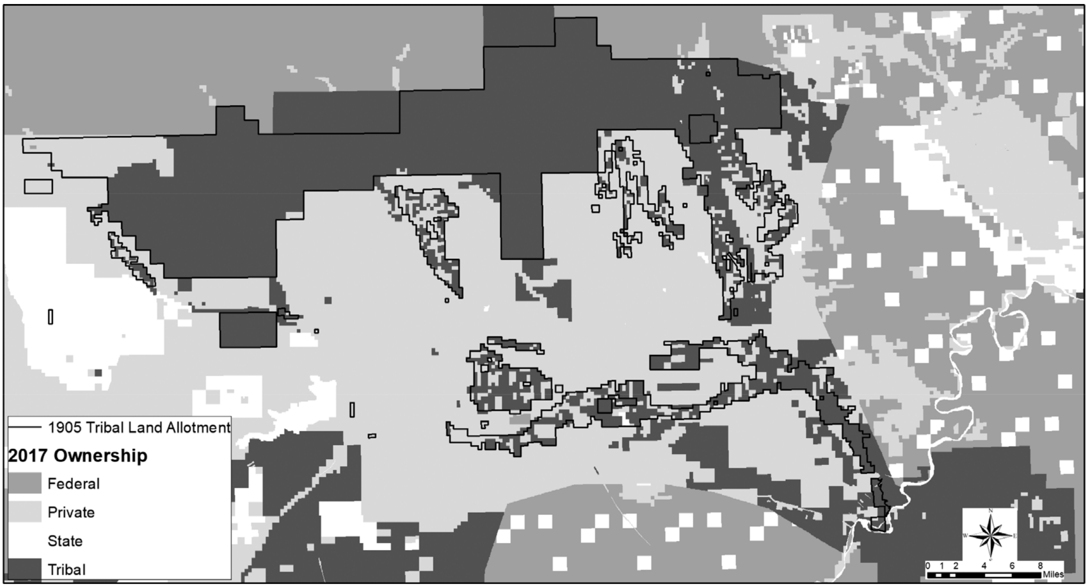

Figure 2. Land ownership map of the Uintah and Ouray Indian reservation relative to the 1905 allotment boundary

Notes: The 1905 allotment is digitized from the Uintah Indian Reservation Disposition map. Much but not all of the land in the figure is within the official boundary of the reservation (reservation boundary not shown). However, land ownership, not the reservation boundary, determines jurisdiction over land-use decisions.

Source: Author's map created with data from the State of Utah.

contributors to Uintah Basin and the state, the tribe experiences the lingering problems associated with having been proclaimed sovereign yet not being treated as such by county, state, and federal entities. This creates disputes between the tribe and these bodies of government over issues such as jurisdiction, double taxation, rights-of-way, and water rights. (Duncan 2000, p. 221)

The Uintah Reservation is located primarily (~85% of total area) in Duchesne and Uintah Counties in Utah. According to the 2012 census of agriculture, of the approximately 3,500 farm operators reporting in these counties, only 122 identified their race as American Indian or Alaska Native. Unfortunately, these statistics are not especially insightful as the reservation itself does not participate in the census of agriculture or report other crop use statistics for agriculture conducted on tribal trust lands. The area around the Uintah Reservation is arid, with agricultural areas receiving approximately 270 mm of precipitation per year, so irrigation is essential for agricultural production. In 2012, 61,000 acres of the approximately 1.2 million acres held in tribal trust were irrigated with 187,000 AF of water. In Duchesne and Uintah Counties, around 205,000 of approximately 5.0 million acres of land were irrigated with 614,000 AF of water (Maupin et al. 2014). Although we do not observe irrigation by source of water use directly on tribal and fee-simple land, in the two relevant counties there is almost no groundwater irrigation.[5]

Water rights are held by both the tribe and fee-simple landowners under Utah's prior appropriation doctrine. Under the *Ute Indian Water Compact* approved in 1980 by the Utah legislature (Utah Code 73–21–1), the state granted the tribe 248,943 acre-feet of consumptive water rights (generally with a priority date of October 3, 1861) to irrigate up to 120,071 acres of tribal land to resolve the tribe's claim for water rights under the doctrine described in Winters v. United States (1908) (Sanchez, Edwards, and Leonard 2019). Water is delivered to both trust and fee-simple farmers around the allotment boundaries by the Uintah Indian Irrigation Project. Alternative suppliers of water in the region include private irrigation companies,

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[5] 2015 USGS water use data shows Uintah County sees 306.94 Mgal/day surface withdrawals for irrigation and 0.13 Mgal/day groundwater withdrawals for irrigation; Duchesne County sees 193.35 Mgal/day surface withdrawals for irrigation and 0.89 Mgal/day groundwater withdrawals for irrigation.

which operate on the periphery of the reservation, and do supply some water to tribal irrigators but are primarily utilized by fee-simple landowners (DOI 2018, 5.1–13). Tribal water rights are held in trust by the federal government, with similar transfer restrictions as trust lands. We return to the issue of these water rights in section 7. We now turn to the setup and results of empirical tests of the predictions laid out in section 2.

Data Construction

We construct variables on agricultural choice, land ownership, land quality, and climate on and around the Uintah Reservation. The unit of observation is a forty-acre parcel from cadastral survey records from the Bureau of Land Management (BLM).[6] Current land ownership type is assigned to each parcel using data from Utah's State Geographic Information Database (SGID). This data set contains surface land ownership—fee simple, tribal, federal, state—as of 2017.

The 1905 allotment boundary is digitized from the Uintah Indian Reservation Disposition map, created in 1905 as discussed previously.[7] The algorithm to calculate the distance to the 1905 boundary is similar to Dell (2010) and Turner, Haughwout, and Van Der Klaauw (2014). Distance to the boundary is calculated as the shortest linear separation between the boundary and each parcel (Black 1999).[8] Examining the map in figure 2, it is apparent that the allotment areas were chosen with some purpose, but the actual boundary is a series of straight lines, suggesting that the precise location of the border is potentially exogenous (Turner, Haughwout, and Van Der Klaauw 2014). Close proximity to the boundary helps ensure that parcels compared across the 1905 allotment are identical except for land ownership designation. We discuss tests on the validity of this assumption below.

Table 1 shows summary statistics and data construction formulae. Summary statistics are provided by current (2017) ownership status for all parcels in our dataset, which is constructed as all parcels within 1.5 miles of the 1905 allotment boundary, excluding those that intersect the boundary. The entire dataset consists of 14,088 observations of forty-acre parcels, of which 4,935 are currently held in tribal trust. In what follows, we briefly describe the study variables.

Agricultural Data

We define all fields that are planted as agricultural land, including hay and pasture. Crop definitions are provided in table A1 in the online supplementary material appendix S1. We classify parcels according to two distinct data sources. The first source is the Water Related Land Use (WRL) dataset published by the Utah Division of Water Resources. The data are created using aerial imagery to delineate the boundaries of all agricultural fields, and then field crews traveled to the location to determine crop and irrigation type.[9] Our original area of 14,088 parcels is not fully covered by the WRL data, although the areas without coverage are generally not used in agriculture. The WRL data classifies 4,682 parcels as agricultural: planted or improved with the potential to be planted.

The second source is the 2015 CropScape-Cropland Data Layer (CDL).[10] The CDL is a raster, geo-referenced, crop-specific land cover data layer produced using satellite imagery. Classification accuracy is generally 85% to 95% for the major, crop-specific land cover categories.[11] The CDL database covers the entire area of study, and 5,287 of the parcels within 1.5 miles of the allotment boundary can be classified as in agricultural production.

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[6] The survey typically divides land into 6-mile-square townships and townships are subdivided into thirty-six one-mile-square sections. Sections can be further subdivided into quarter sections, quarter-quarter sections, and sometimes irregular government lots.

[7] The historical disposition map is digitized by hand. Hence, the grid of the historical map does not fully match the PLSS quarter-quarter section grid. Admittedly, there is some room for error, and thus bias, with hand digitization. To alleviate this problem, we exclude the parcels located on the 1905 allotment boundary.

[8] Dell (2010) used the Euclidean distance as the single-dimensional specification because her dataset does not include enough observations within a close proximity. In her setting, the elevation and other statistics are not identical. Instead of using Euclidean distance, Black (1999) used the shortest linear distance because the unit of observation in her paper is small enough for her to include enough observations within 0.15 miles bandwidth.

[9] We use the 2017 dataset, which consists of data collected between 2011 and 2016. The survey year for the areas around the Uintah Reservation is listed as 2016. We initially used 2012 data with similar results. The data is available for the Uintah region for 1992, 2000, 2006, 2012, and 2016.

[10] CropScape dataset is hosted by the National Agricultural Statistics Service, United State Department of Agriculture. These data (agricultural land layer) are available for the region from 2008–2018 at: https://nassgeodata.gmu.edu/CropScape/.

[11] More information on classification and accuracy is available at: https://www.nass.usda.gov/Research_and_Science/Cropland/sarsfaqs2.php.

Table 1. Summary Statistics

		<1.5 Miles 1905 allotment boundary			
		Observation		Mean	
	Formula	Tribal	Non-tribal	Tribal	Non-tribal
Agricultural rate (CDL)	$AgRate = \frac{CDL\ Ag\ Land}{Total\ Land}$	4,935	9,153	0.117	0.107
				(0.238)	(0.225)
Agricultural rate (WRL)	$AgRate = \frac{WRL\ Ag\ Land}{Total\ Land}$	4,935	9,153	0.195	0.205
				(0.362)	(0.347)
Irrigation rate	$IrrRate = \frac{Irrigated\ Land}{WRL\ Ag\ Land}$	1,426	3,256	0.390	0.424
				(0.407)	(0.372)
Sprinkle-irrigation rate	$SprkRate = \frac{Sprinkler\ Land}{Irrigated\ Land}$	1,035	2,727	0.117	0.312
				(0.275)	(0.350)
High-value cropland rate (CDL)	$CDLRate = \frac{CDL\ Hcrop\ Land}{CDL\ Ag\ land}$	1,761	3,526	0.058	0.108
				(0.170)	(0.218)
High-value cropland rate (WRL)	$WRLRate = \frac{WRL\ Hcrop\ Land}{WRL\ Ag\ Land}$	1,426	3,256	0.011	0.024
				(0.083)	(0.122)

Notes: Summary statistics for the six outcome variables within 1.5 miles of 1905 allotment boundary by current land ownership status. Statistics include all observations, including land that has changed hands since 1905. Standard errors are provided in parentheses.

Irrigation Data

Irrigation rate and sprinkler irrigation rate data come from the WRL data. Of the 4,682 agricultural parcels, 3,762 have some area irrigated. There are two primary irrigation methods used in the region: sprinkler and flood.[12] Parcel level overall irrigation and sprinkler irrigation rates are captured by first extracting the area of each parcel in each category. We then divide the area of the parcel that is irrigated by the area in agricultural production to get the irrigation rate. We obtain the sprinkler irrigation rate by dividing the area of a parcel in sprinkler irrigation by the area that is irrigated. As such, our measures are nested: the proportion irrigated given the land is in agricultural production, and the proportion that utilizes sprinkler irrigation, given the land is irrigated.

Figure 3 depicts the area of agricultural land (WRL data) in the study region categorized by whether it is irrigated or not. The boundary line is the 1905 allotment boundary. Visual inspection suggests that the large, contiguous region in the northern part of the allotment is distinctly discontinuous in terms of agricultural land. This area of the allotment was and remains designated as grazing land by the tribe. Importantly, this land use choice does not affect our measurement of irrigation or sprinkler irrigation across the boundary, because as non-agricultural land, this area is excluded from any of the rate calculations.

Figure 4 shows the sprinkler-irrigation map relative to 1905 land ownership. In this map, the difference across the 1905 boundary in sprinkler rates is apparent, particularly in the allotment areas that have retained larger amounts of tribal trust land (see figure 2). The descriptive statistics in table 1 corroborate this observation.

High-Value Crops

We obtain crop type data from the CDL and WRL data sets described above. We classify crops into high-value, such as corn and beans, and low-value categories, such as alfalfa, hay, and pasture (see table A1 in the online supplementary material appendix S1). Table 1 shows that more high-value crops are grown on average on fee-simple land than tribal land in both data sets. Figure 5 illustrates the crop value distribution relative to the 1905 allotment using the WRL data set.

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[12] A third category, drip-irrigated acreage, is also provided but it is so rarely used that we drop it from the analysis of irrigation type.

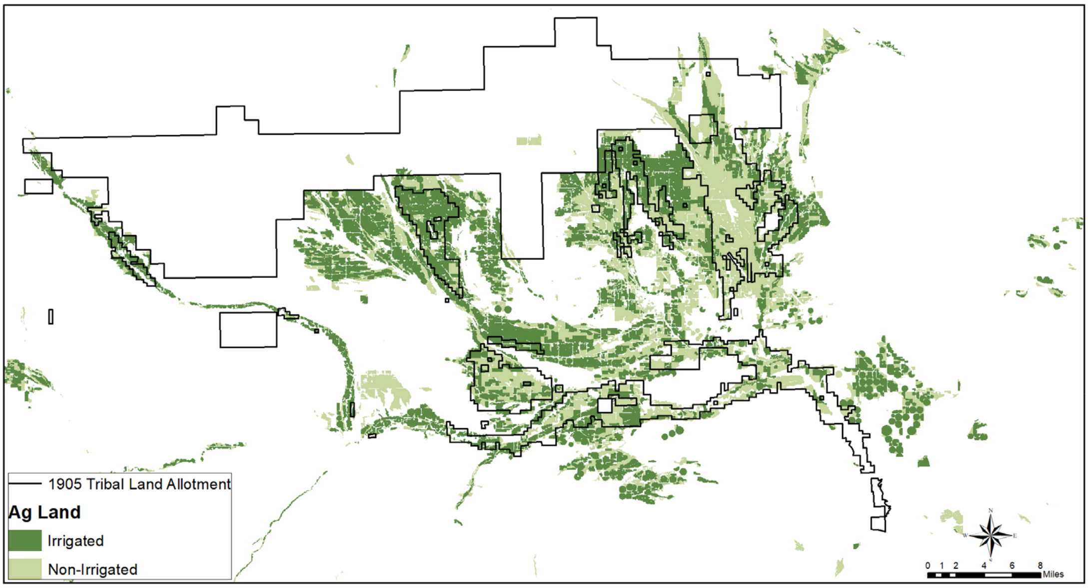

Figure 3. Agricultural land in 2017 near the Uintah Indian reservation relative to the 1905 allotment boundary

Notes: The entire shaded area of the map represents the parcels in agricultural land (WRL data), with darker shading being land classified as irrigated. White areas are excluded from all analyses. The 1905 allotment is digitized from the Uintah Indian Reservation Disposition Map.
Source: Authors' map created with data from the State of Utah.

Controls

We obtain a soil quality raster map from the Iowa State University Geospatial Laboratory. The raster provides a productivity index (PI), which is an ordinal measure of soil productivity ranging from 0 (least productive) to 19 (most

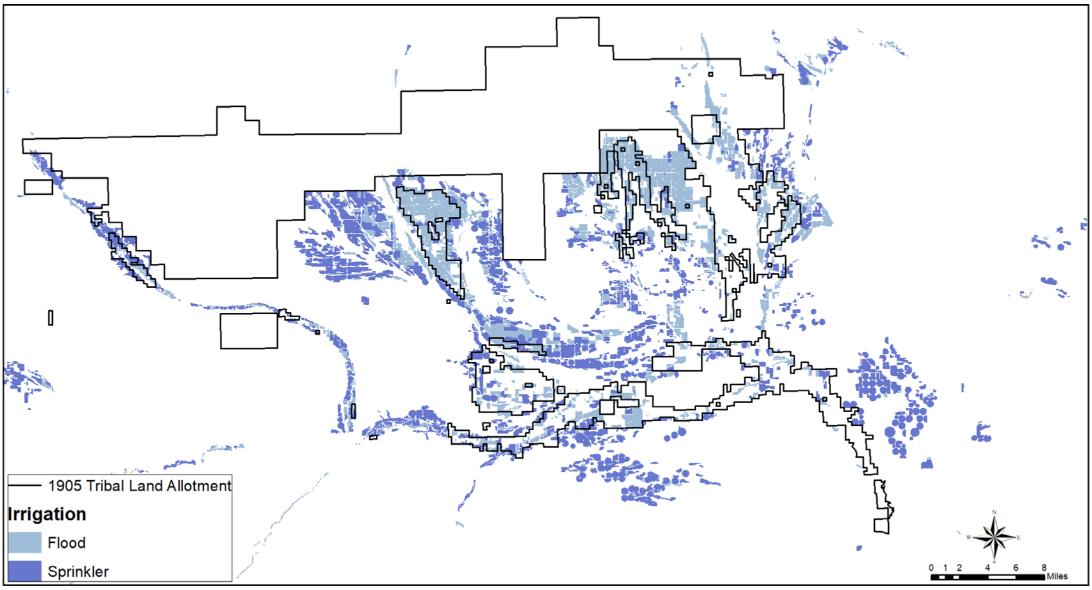

Figure 4. Irrigated land in 2017 near the Uintah reservation relative to the 1905 allotment boundary

Notes: The entire shaded area of the map represents the parcels in agricultural land (WRL data) that are irrigated, with darker shading being land classified as sprinkler irrigation. White areas are excluded from the irrigation analyses. The 1905 allotment is digitized from the Uintah Indian Reservation Disposition map.
Source: Authors' map created with data from the State of Utah.

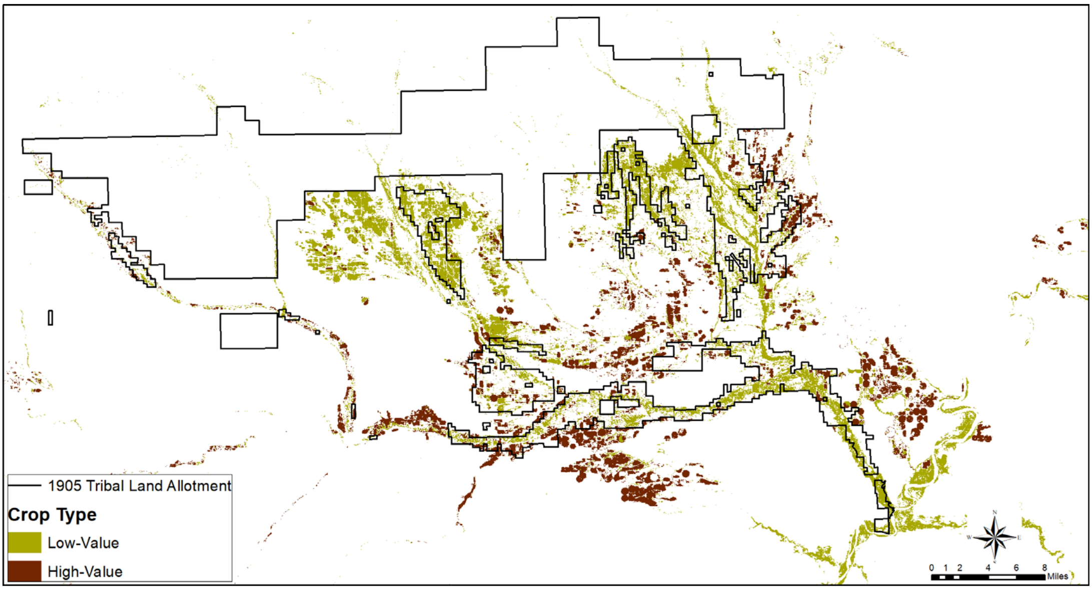

Figure 5. Cropland in 2017 near the Uintah reservation relative to the 1905 allotment boundary

Notes: The entire shaded area of the map represents land classified as in crop production by the CropScape (CDL) data layer, with darker shading being land classified as high-value crops. White areas are excluded from the crop-type analyses. The 1905 allotment is digitized from the Uintah Indian Reservation Disposition map.
Source: Authors' map created with data from USDA.

productive), based on soil taxonomy information (Schaetzl, Krist Jr., and Miller 2012). Because the index is ordinal and some parcels may contain two or more different types of soil productivity indices, we cannot calculate the mean soil productivity of each parcel as a continuous variable. Following Schaetzl, Krist Jr., and Miller (2012), we assign the soil productivity rank of the largest share of each parcel, ensuring a unique soil productivity rank.

We measure distance to river by calculating the shortest linear distance from the edge of each parcel to the nearest river, obtained from the National Hydrology Database (NHD).[13]

In order to ensure that we are comparing parcels in close geographic proximity along the regression discontinuity line, we control for township fixed effects—townships being 6x6-mile blocks (see footnote 6)—which is similar to Hagerty (2019) who uses 5 km boundary segments to construct comparisons. To further control for geographic effects, we also consider parcel mean elevation, slope, and the latitude and longitude of parcel centroids. The mean elevation and slope of each parcel is calculated by overlaying PLSS parcels on three-arc second resolution elevation data. The elevation data is obtained from the NASA Shuttle Radar Topographic Mission (SRTM) 90 m Digital Elevation Dataset.[14]

Temperature and precipitation raster datasets are collected from the PRISM Climate Group at Oregon State University and are annual averages for years 1981–2010. The raster dataset provides the value of climate statistics at 800 m resolution. We obtain three temperature indicators—annual daily mean temperature, mean daily maximum temperature, and mean daily minimum temperature—as well as mean annual precipitation.[15]

Empirical Design

The spatial RD design has been broadly implemented in different contexts in recent years to study intervention or treatment effects (Bayer, Ferreira, and McMillan 2007; Dell 2010; Dachis, Duranton, and Turner 2011; Grout, Jaeger, and Plantinga 2011; Dell 2015; Card and Giuliano

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[13] River location and soil quality relative to the 1905 allotment boundary is displayed in figure C1 in the online supplementary material.

[14] Elevation relative to the 1905 allotment boundary is shown in figure C2 in the online supplementary material.

[15] Precipitation and the daily average mean temperature relative to the 1905 allotment boundary are shown in figures C3 and C4, respectively, in the online supplementary material.

2016; Pan, Smith, and Sulaiman 2018). Because the ownership status of parcels in 2017 may be determined in part by characteristics that also determine suitability for irrigated agriculture, we exploit the 1905 land allotment to explore the impacts of tribal trust ownership on current agricultural outcomes.

Sharp RD

Our first strategy utilizes a sharp RD design across the 1905 boundary. Because land ownership classification might have changed since 1905, not all parcels in the neighborhood of the border remain as originally allocated. Therefore, we apply the sharp RD design only on the lands that have not changed land ownership classification since 1905.

The sharp RD design relies on two identifying assumptions. First, the local randomization assumption requires that within a bandwidth of prespecified size around the 1905 allotment boundary, whether or not an observation receives the treatment is essentially randomly determined. This assumption implies that all the relevant variables should vary smoothly at the 1905 allotment boundary, and observations located just outside of the 1905 allotment boundary should be an appropriate counterfactual for those located just inside the boundary. To assess the validity of this requirement, we conduct the smoothness test for a group of control variables related to agricultural productivity, as shown in table 2, for six different bandwidth choices (0.25, 0.5, 0.75, 1, 1.5 miles, and optimal miles).[16] Parcels across the 1905 allotment boundary appear identical in elevation, temperature, and soil productivity measures in small bandwidth choices, consistent with the identification assumption. We also observe some systematic differences across the boundary. Tribal trust parcels are closer to rivers on average, which is an artifact of the BIA agents, discussed earlier, attempting to find allotment lands with adequate access to water, one of their key stated concerns. Tribal trust parcels also appear drier, with the average difference on the order of 1–2 centimeters per year. Both differences would lead to an expectation of more irrigation on tribal lands, which have more water access and see slightly lower natural rates of rainfall.

The second identifying assumption of the sharp RD design is a continuity assumption, which requires that the only change that occurs at the 1905 allotment boundary is the shift in treatment status. McCrary (2008) proposed an estimator designed to test the continuity of the density function of the forcing (assignment) variable. He argued that if observations are able to sort themselves across a given bandwidth, then the observations just to the left of the cut off are likely to be substantially different from those to the right. We implement the McCrary's sorting test on four sets of parcels: the full sample, agricultural land (WRL), irrigation land (WRL), and agricultural land (CDL). The sorting test results are reported in figures A6–A9 in the online supplementary material appendix S1, showing the continuity test of the 1905 allotment boundary. It is apparent that the number of observations is continuous within a 1-mile bandwidth choice in agricultural land (both WRL and CDL) and irrigation land (WRL). The continuity assumption holds within 0.5 miles in full sample with all observations. This shows that the continuity assumption is reasonably satisfied in our study.

We call the treatment $Allotment1905_i$, which is an indicator equal to 1 if parcel i is within x miles inside of boundary and equal to 0 if parcel i is within x miles outside of boundary. The running (assignment) variable is $dist1905_i$, representing the shortest linear distance of parcel i from the 1905 allotment boundary ($\overline{dist1905}$). The threshold value (boundary position) $\overline{dist1905}$ is equal to 0 in this model. Because the assignment to treatment is sharply determined by the 1905 allotment boundary, the relationship between the treatment indicator $Allotment1905_i$ and the running variable $dist1905_i$ is established by:

$$Allotment1905_i = \begin{cases} 1\, if\ dist1905_i \geq \overline{dist1905} \\ 0\, if\ dist1905_i < \overline{dist1905} \end{cases}$$

The sharp RD design model is specified as follows:

$$(5)\quad R1905_i = \alpha + \beta_1 Allotment1905_i + \beta_2 f\left(dist1905_i - \overline{dist1905}\right) + \beta_3 f\left(dist1905_i - \overline{dist1905}\right) \cdot Allotment1905_i + \boldsymbol{X}_i{}'\varphi + \varepsilon_i$$

In equation 5, $R1905_i$ is the outcome variable of interest; $\boldsymbol{X}_i$ is a vector of controls that includes climate characteristics, elevation, soil productivity,

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[16] The smoothness tests in table 2 are obtained using the second order local polynomial regression. See tables A7–A13 and figure A1 in the online supplementary material for detailed results from first, second, third, and fourth order local polynomial regressions.

Table 2. 1905 Allotment Boundary Smoothness Test

	Estimated average treatment effects						
Sample within	<0.25 Miles	<0.5 Miles	<0.75 Miles	<1 Miles	<1.5 Miles	Optimal bandwidth	Optimal miles
Soil Productivity Index							
Allotment1905	−0.280 (0.182)	−0.140 (0.159)	−0.323 (0.154)**	−0.340 (0.153)**	−0.289 (0.145)**	−0.197 (0.122)	1.864
Elevation							
Allotment1905	−7.116 (25.292)	−29.737 (23.237)	−29.735 (23.428)	−28.146 (23.561)	−28.114 (22.568)	−29.170 (22.134)	1.011
Distance to river							
Allotment1905	−0.084 (0.042)**	−0.124 (0.040)`	−0.098 (0.039)**	−0.093 (0.038)**	−0.083 (0.035)**	−0.074 (0.033)**	1.243
Average daily mean temperature							
Allotment1905	0.077 (0.104)	0.157 (0.096)	0.157 (0.097)	0.148 (0.098)	0.146 (0.093)	0.151 (0.092)*	1.019
Average daily max temperature							
Allotment1905	0.084 (0.140)	0.212 (0.127)*	0.200 (0.129)	0.188 (0.130)	0.187 (0.125)	0.182 (0.123)	0.993
Average daily min temperature							
Allotment1905	0.069 (0.075)	0.101 (0.070)	0.113 (0.071)	0.108 (0.071)	0.104 (0.067)	0.105 (0.066)	1.111
Average annual precipitation							
Allotment1905	−10.760 (8.295)	−19.001 (7.578)**	−20.510 (7.689)***	−20.155 (7.718)***	−19.965 (7.393)***	−19.865 (7.112)***	1.128

Notes: Smoothness test across the 1905 boundary for seven different control variables using the second order local polynomial regression. All regressions include township fixed effects. Five different fixed bandwidth choice results are listed, including an optimal bandwidth choice calculated based on Calonico, Cattaneo, and Titiunik (2014). Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Standard errors constructed using a heteroscedasticity-robust nearest neighbor variance estimator are shown in parentheses.

distance to river, and township fixed effects; $f(\cdot)$ is a polynomial distance function; and ε_i is an error term with standard properties.[17] The parameter of interest is β_1, which captures the treatment (institutional) effect. An estimate of average treatment effect is thus obtained by comparing the average of $R1905_i$ for those just above and those just below $\overline{dist1905}$, controlling for distance and other covariates.

Fuzzy RD

Despite the apparent smoothness and continuity across the 1905 boundary for parcels that remain in their original allocation, we may still be concerned that land on only one side of the boundary saw ownership changes based on attributes correlated to agricultural productivity and/or suitability for irrigation. Recall that more than 30,000 acres of Uintah agricultural land were sold or leased to non-Indians (Duncan 2000, p.207), which considerably altered the nature of tribal trust land inside the original 1905 allotment boundary. Soil productivity, elevation, distance to river, and climate characteristics, to the extent they were known, may have affected whether a parcel was sold out of tribal trust.

We define a variable $Uintah2017_i$ as a dummy for land in tribal trust in 2017. We cannot compare the average treatment effect of tribal trust (in 2017) directly because it may be endogenously determined. We instead implement a fuzzy RD design, using the 1905 allotment boundary ($Allotment1905_i$) as an instrument for current land ownership. There are two basic assumptions that must hold. First, the relevance condition: $Allotment1905_i$ should have the potential to affect the probability that $Uintah2017_i = 1$. From figure 2, it is clear that the 2017 tribal trust land is related to the 1905 allotment boundary, and the first-stage tests are discussed below.

Second, the exclusion condition: $Allotment1905_i$ has to be unrelated to $R2017_i$, our outcome variables of interest, conditional on $Uintah2017_i$ and other controls. Although not directly testable, we believe this is a plausible assumption for several reasons. First, the 1905 allotment utilized several straight-line boundaries, which were unlikely to have been selected in a way that is correlated with future irrigation scheme. Second, the allotment borders were assigned before the irrigation infrastructure was built on the Uintah reservation. Moreover, the smoothness tests across the 1905 allotment boundary indicate small differences in select land and climate characteristics that might have been observable at the time of assignment (see table 2). Finally, to guard against the possibility that unseen factors are responsible for the results, we include controls for many of the potential factors affecting agricultural productivity and irrigation suitability.

The fuzzy RD design is a two-stage estimation process. The first stage involves regressing the 2017 treatment indicator ($Uintah2017_i$) on the 1905 boundary ($Allotment1905_i$, the instrument) and the additional controls ($\boldsymbol{X}_i$):

$$\begin{aligned}(6)\quad Uintah2017_i = {} & \lambda + \gamma_1 Allotment1905_i \\ & + \gamma_2 g\left(dist1905_i - \overline{dist1905}\right) \\ & + \gamma_3 g\left(dist1905_i - \overline{dist1905}\right) \\ & \cdot Allotment1905_i + \boldsymbol{X}_i{}'\varphi + \nu_i\end{aligned}$$

where $g(\cdot)$ is a polynomial distance function. Given that the dependent variable in equation 6 is discrete, we fit a generalized linear model with a probit function. Once we estimate the first stage equation, we use the fitted values, $\widehat{Uintah}2017_i$, to evaluate the average treatment effect in the second stage:

$$\begin{aligned}(7)\quad R2017_i = {} & \delta + \beta_1 \hat{Uintah}2017_i \\ & + \beta_2 h\left(dist1905_i - \overline{dist1905}\right) \\ & + \beta_3 h\left(dist1905_i - \overline{dist1905}\right) \\ & \cdot Allotment1905_i + \boldsymbol{X}_i{}'\varphi + \varepsilon_i\end{aligned}$$

where $h(\cdot)$ is a polynomial distance function and the treatment effect is captured by β_1. The covariate vector $\boldsymbol{X}_i$ includes the same set of controls as under sharp RD model.

Estimation, Bandwidth, and Functional Form Selection

Identification of the local spatial RD treatment effect requires data points in the immediate neighborhood around the border. As the neighborhood expands, the estimate of the average treatment effect becomes less noisy, while the risk of bias of the estimate increases, as the trends in other variables across the discontinuity may influence the estimate. Although

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[17] We report standard errors constructed using a heteroscedasticity-robust nearest neighbor variance estimator. This is in the spirit of Pan, Smith, and Sulaiman (2018), who use standard errors clustered at the village level, which do not explicitly control for spatial correlation. In the robustness analysis, we consider spatially robust standard errors and show that our main findings are qualitatively unaffected.

some of these confounding effects can be controlled for using additional regressors and polynomial order trends in distance, the selection of the bandwidth around the discontinuity remains an important consideration. We employ a data-driven, mean square error (MSE)-optimal bandwidth selection procedure of Calonico, Cattaneo, and Titiunik (2014, 2015) and verify the robustness of the results to different arbitrary choices of bandwidth. Specifically, we analyze the data with 0.25-mile, 0.5-mile, 0.75-mile, 1-mile and 1.5-mile bandwidths around the 1905 allotment boundary, using both sharp and fuzzy RD designs, in addition to the optimal bandwidth.

We implement the nonparametric, bias-corrected robust inference procedure of Calonico, Cattaneo, and Titiunik (2014) to select the functional form for the running variables, that is, $f(\cdot)$, $g(\cdot)$, and $h(\cdot)$, and, more importantly, to study the discontinuities at the boundary more closely. This approach is appropriate, and recommended, for contexts with a large number of observations close to the treatment threshold (Imbens and Lemieux 2008). The nonparametric technique has the advantage of not relying on functional form assumptions and is commonly used in spatial RD design (Dell 2010). Standard errors for non-parametric estimates are obtained using a heteroscedasticity-robust nearest neighbor variance estimator.

To obtain the nonparametric function of the running variable, we fit the first, second, third, and fourth order local polynomial regressions on either side of the cutoff (i.e., boundary). It is common practice in regression discontinuity analysis to control for third, fourth, or higher order polynomials of the forcing variable within a sliding window to accommodate highly nonlinear functional forms. However, Gelman and Imbens (2019) argue that higher order polynomials are ill-suited for regression discontinuity analysis because they lead to noisy estimates, sensitivity to the degree of the polynomial, and poor coverage of confidence intervals. Instead, they recommend using estimators based on local linear (first order) or quadratic (second order) polynomials. Consequently, we present the results from second order local polynomial regressions in the paper and include the first, third, and fourth order local polynomial regression results in the online supplementary material (tables A2-A6 and figures A2-A5, A10 in the online supplementary material appendix S1) as a robustness check.

Results

We begin by testing the 1905 allotment boundary impact on agriculture and crop choice variables using the sharp RD approach.

Sharp RD Results

Table 3 reports estimates of the average treatment effect using different bandwidth choices and a second-order local polynomial regression. First, we estimate the effect on agricultural rate (rows 1–2), using both CDL and WRL datasets. Column 1 of table 3 limits the sample to parcels within 0.25 miles of the 1905 allotment boundary, and columns 2–5 restrict it to fall within 0.5, 0.75, 1, and 1.5-miles, respectively. Column 6 reports the allotment effect with the optimal bandwidth, and column 7 indicates the optimal bandwidth (in miles). Rows 3–6 present the results for irrigation rate, sprinkler-irrigation rate, and high-value cropland rate (CDL and WRL datasets) as the dependent variable, respectively.[18]

There are no apparent differences in rates of agriculture and irrigation on allotted lands. Conditional on being irrigated, however, allotted lands see lower rates of sprinkler irrigation, in the range of 21% to 24% points. These negative effects remain statistically significant at the 1% level across all bandwidths. Hence, the results consistently indicate that there is a negative effect of being inside the 1905 allotment border on investment in sprinkler irrigation. Moreover, the allotment coefficients are similar across the four specifications of the sharp RD model,[19] and we are unable to reject that they are statistically identical.

The coefficients for high-value crops show a statistically significant difference across the 1905 allotment boundary using both the CDL and WRL data. The negative allotment coefficients range from −0.095 to −0.100 in the CDL dataset and −0.025 to −0.037 in the WRL dataset.[20] Although both CDL and WRL data show a divergence across the boundary, the

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[18] Tables A2 to A5 in the online supplementary material examine the robustness of the main specification to first, third, and fourth order local polynomial specifications.

[19] Table A4 in the online supplementary material shows the sharp RD results of sprinkler irrigation rate using first, second, third, and fourth order local polynomial regressions. The negative allotment effect (ranging from −0.192 to −0.243) is statistically significant at the 1% level across all specifications. This is also apparent from figure A4 in the online supplementary material.

[20] This negative effect still exists when we choose the different order local polynomial regressions. See tables A5-1 and A5-2 in the online supplementary material.

CDL estimate is about twice as large as the WRL estimate. This is due to differences in how these measures are constructed, which leads the CDL dataset to show higher baseline levels of high-value crop acreage (see table 1). Both results suggest that tribal trust land has lower levels of high-value crops.[21]

The sharp RD design, however, is not the ideal empirical framework in this setting, as discussed above. In particular, because land could have changed hands since 1905, in our sharp RD analysis we focus only on the lands where ownership does not change. Figure 6 plots outcomes based on land ownership transition since 1905, relative to the original allotment boundary. The figure demonstrates the strong selection issue we must overcome. Land within the original allotment (on the right side of each panel) that moves into fee simple is relatively high quality land near the allotment boundary, whereas land that was originally outside the allotment boundary and that was returned to the tribe (left side of panels) is relatively lower quality near the border. The continuous line represents the land that never changed hands. Across all of our measures there appears to be a clear selection issue where land that is more likely to be in agriculture and high-value agriculture has become fee simple since 1905. Both the use of different polynomial orders and township controls, as well as land-quality controls, help us alleviate the selection issue to some extent. However, a more rigorous approach to deal with the issue of land ownership changes is through the implementation of the fuzzy RD design, which retains all parcels and utilizes only variation from the 1905 allotment boundary to identify the model.

Fuzzy RD Results

Table 4 presents the first-stage relationship between the 1905 allotment lands ($Allotment1905_i$) and the probability that a parcel is in tribal trust in 2017 ($Uintah2017_i$). Because the number of observations is different depending on the land type examined, we report the first stage for all four subsamples.[22] It is evident that there is a strong discontinuity across the 1905 allotment boundary for whether land in 2017 is in tribal trust or not. Although the probability of treatment clearly jumps at the cutoff, the treatment probability increases by less than one, and hence the fuzzy RD approach allows us to recover an average treatment effect.

Table 5 reports estimates of the average treatment effect from the two-stage, fuzzy RD design using different bandwidth choices and a second-order local polynomial regression. Results are similar to those from the sharp RD design. Although the CDL classification suggests the rate of agriculture on trust land is around eight percentage points higher (0.065 to 0.116), the WRL estimates do not show statistically significant differences for smaller bandwidths. Similar to the sharp RD results, the rate at which land is irrigated is similar across the boundary, but the area of land in sprinkler irrigation and high-value crops is considerably lower on tribal trust land.

Conditional on land being irrigated, the tribal boundary effect shows that the sprinkler-irrigation rate is around thirty-two percentage points lower (−0.294 to −0.338) within the reservation. The treatment coefficients are economically similar to each other across different bandwidth choices.[23] Similarly, given crop production, tribal trust land sees significantly less area in high-value crops; approximately ten percentage points (−0.088 to −0.108) lower in the CDL dataset and 4.3 percentage points (−0.032 to −0.055) lower in the WRL dataset. The average treatment estimates are consistent across different bandwidth choices and choice of controls. The fuzzy RD results are generally slightly greater in magnitude, but in the same direction, as the sharp RD results and both sets of results are consistent with tribal trust land not receiving investment in irrigation at the levels seen on fee-simple land.

Robustness Checks

To verify the sensitivity of the main estimation results to the order of a local polynomial regression, we consider different choices (first, second, third, and fourth) for both the sharp and fuzzy RD models. Our results are not sensitive to the functional form of the distance-to-boundary controls.[24]

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[21] The sharp RD results for high-value cropland rate are illustrated in figures A5-1 to A5-2 in the online supplementary material. Each subfigure corresponds to a particular choice of the order of a local polynomial regression.

[22] Tables A6-1 to A6-4 in the online supplementary material report the first-stage results of fuzzy RD using first, second, third, and fourth order local polynomial regressions, respectively. Figures A10-1 to A10-4 in the online supplementary material plot the visualization of the first-stage results.

[23] Tables A14 to A17 in the online supplementary material provide the main fuzzy RD results using first, second, third, and fourth order local polynomial regressions.

[24] These results are provided in Appendix A of the supplementary online material.

Table 3. Nonparametric Sharp RD Results

Sample within	Estimated average treatment effects						
	<0.25 Miles	<0.5 Miles	<0.75 Miles	<1 Miles	<1.5 Miles	Optimal bandwidth	Optimal Miles
Agricultural rate (CDL)							
Allotment1905	0.010 (0.019)	0.012 (0.017)	0.009 (0.016)	0.010 (0.016)	0.015 (0.015)	0.020 (0.013)	1.651
Agricultural rate (WRL)							
Allotment1905	−0.026 (0.030)	−0.026 (0.027)	−0.037 (0.026)	−0.033 (0.026)	−0.027 (0.024)	−0.027 (0.020)	1.781
Irrigation rate							
Allotment1905	−0.088 (0.047)*	−0.055 (0.044)	−0.051 (0.043)	−0.048 (0.042)	−0.050 (0.040)	−0.048 (0.043)	1.033
Sprinkle-irrigation rate							
Allotment1905	−0.211 (0.039)***	−0.209 (0.037)***	−0.224 (0.036)***	−0.227 (0.036)***	−0.243 (0.033)***	−0.228 (0.035)***	1.112
High-value cropland rate (CDL)							
Allotment1905	−0.100 (0.019)***	−0.100 (0.018)***	−0.098 (0.017)***	−0.100 (0.017)***	−0.096 (0.016)***	−0.095 (0.017)***	0.976
High-value cropland rate (WRL)							
Allotment1905	−0.037 (0.010)***	−0.037 (0.009)***	−0.031 (0.009)***	−0.030 (0.009)***	−0.026 (0.008)***	−0.025 (0.008)***	1.264

Notes: The second order local polynomial sharp RD regression results for six different dependent variables. Five different fixed bandwidth choice results are listed, including an optimal bandwidth choice calculated based on Calonico, Cattaneo, and Titiunik (2014). All regressions include controls for climate, elevation, soil productivity, distance to river, and township fixed effects. Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Standard errors constructed using a heteroscedasticity-robust nearest neighbor variance estimator are shown in parentheses.

We also consider an alternative specification for the outcome variables of interest. Specifically, we construct binary variables for agricultural land, irrigation land, sprinkler-irrigation land, and high-value cropland. For instance, the binary variable for agricultural land is equal to 1 if any agricultural activity takes place within the parcel and 0 otherwise. The binary variables for other outcome measures are defined analogously. The regression results using these binary outcome variables are similar to those reported above: sprinkler-irrigation rates and high-value cropland rates remain lower in tribal trust land in these specifications. These results are included in tables B1-1 to B1-3 in the supplementary online material.

Another potential issue arises from the inclusion of grazing land designated for tribal use, which may have been of lower quality. We run the main regression specifications from the paper on a subsample that excludes these lands. See tables B2-1 to B2-3 in the supplementary online material. The results on the sprinkler-irrigation rate are again similar to our main results. The tribal trust lands have statistically significant, lower rates of sprinkler irrigation in both the sharp and fuzzy RD design. The high-value cropland rates are also similar to our main findings.

In the appendix D in the online supplementary material appendix S1, we add three additional geographical controls to our main specifications: parcel slope, and the latitude and longitude of parcel centroids. There are some differences in the sharp RD specifications, indicating more clearly that the lands that did not leave tribal trust are selectively worse than the lands that remained in fee simple, once the lands that moved are excluded. However, the magnitude and statistical significance of the fuzzy RD regressions—the preferred estimation framework—including these additional controls match those from the original specification.

Finally, we run a robustness check that controls for spatial dependencies in our standard errors (Conley 1999), which requires a standard ordinary least squares (OLS) regression. Therefore, we re-run all our specifications using an OLS model, for which point estimates remain similar in sign and magnitude to the nonparametric results. Comparing traditional standard errors with those that are spatially robust suggests that traditional standard errors slightly overstate statistical significance

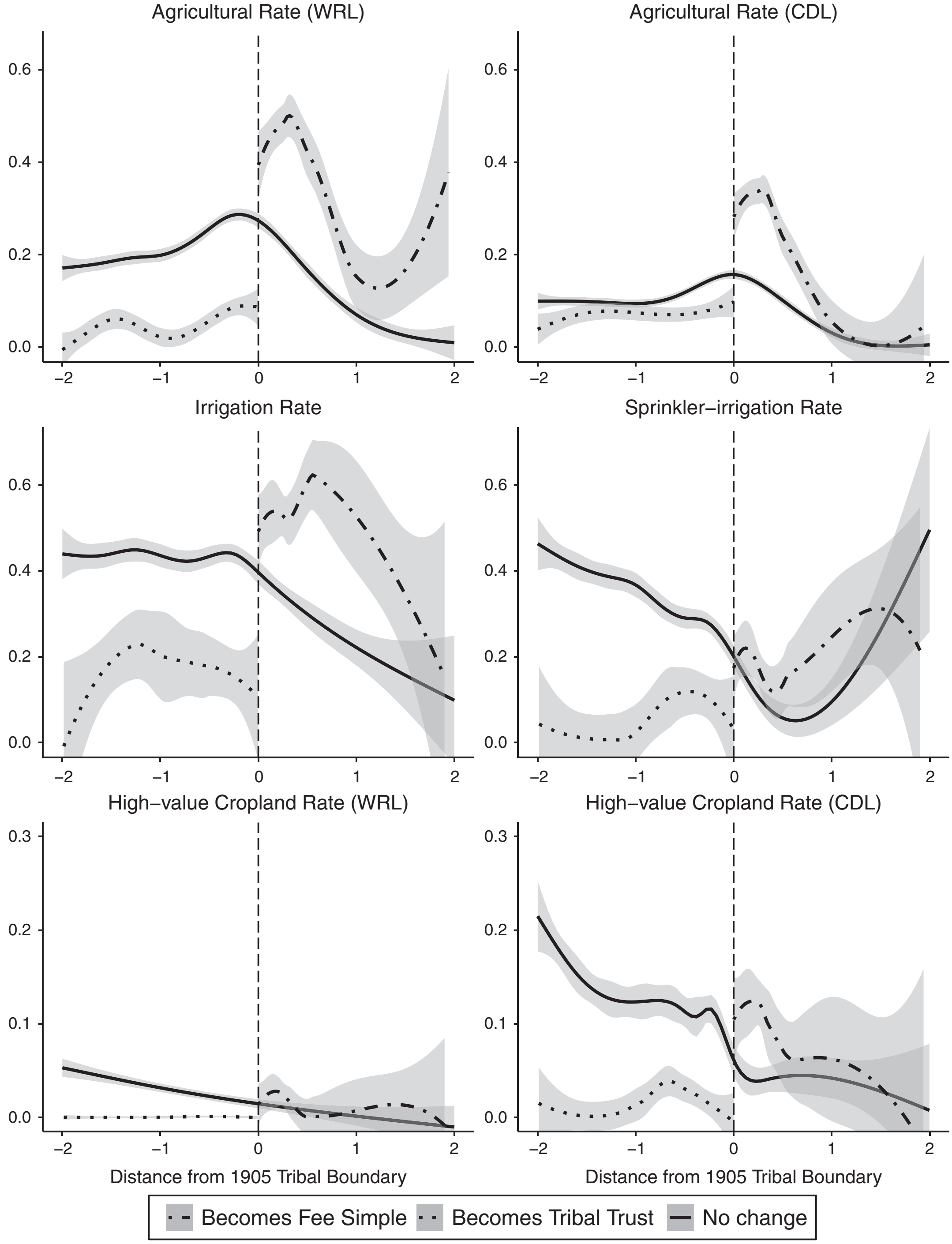

Figure 6. Agriculture and crop characteristics as a function of distance to allotment boundary

Notes: Mean values for all parcels in each dataset are plotted relative to current ownership using the second order local polynomial regression. The positive range of the horizontal axis corresponds to land allotted to the tribe, whereas the negative range corresponds to land that was opened for white settlement in 1905.

in our setting; however, the main findings on sprinkler irrigation and high-value crop rates are generally statistically significant at the 1% level under both standard error assumptions. Results of OLS regressions, with both types of standard errors reported, are shown in the appendix E in the online supplementary material appendix S1.

Table 4. Nonparametric First-stage Results of Fuzzy RD

Sample within	2017 tribal boundary <0.25 Miles	<0.5 Miles	<0.75 Miles	<1 Miles	<1.5 Miles	Optimal bandwidth	
Full sample							Optimal miles
Allotment1905	0.599 (0.030)***	0.605 (0.027)***	0.592 (0.026)***	0.589 (0.026)***	0.581 (0.024)***	0.560 (0.022)***	1.468
Agricultural land only (WRL)							
Allotment1905	0.537 (0.039)***	0.565 (0.037)***	0.559 (0.036)***	0.561 (0.036)***	0.571 (0.035)***	0.563 (0.036)***	1.450
Irrigated land only (WRL)							
Allotment1905	0.533 (0.042)***	0.563 (0.041)***	0.556 (0.040)***	0.554 (0.040)***	0.566 (0.038)***	0.550 (0.042)***	1.043
Agricultural land only (CDL)							
Allotment1905	0.529 (0.041)***	0.560 (0.038)***	0.549 (0.038)***	0.549 (0.037)***	0.564 (0.036)***	0.564 (0.036)***	1.098

Notes: The second order local polynomial first-stage regression results of fuzzy RD design. There are four first-stage regressions for six second-stage regressions. The WRL and CDL full-sample regressions have the same first-stage. The WRL agricultural land first-stage regression is used for both the irrigated land and high-value crop regressions. Five different fixed bandwidth choice results are listed, including an optimal bandwidth choice calculated based on Calonico, Cattaneo, and Titiunik (2014). All first-stage regressions include controls for climate, elevation, soil productivity, distance to river, and township fixed effects. Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Standard errors constructed using a heteroscedasticity-robust nearest neighbor variance estimator are shown in parentheses.

Table 5. Nonparametric Fuzzy RD Results

Sample within	Estimated average treatment effects <0.25 Miles	<0.5 Miles	<0.75 Miles	<1 Miles	<1.5 Miles	Optimal bandwidth	
Agricultural rate (CDL)							Optimal miles
Tribe2017	0.084 (0.029)***	0.072 (0.028)***	0.065 (0.027)**	0.067 (0.027)**	0.080 (0.027)***	0.116 (0.023)***	1.726
Agricultural rate (WRL)							
Tribe2017	0.064 (0.044)	0.061 (0.043)	0.053 (0.041)	0.057 (0.041)	0.067 (0.040)*	0.075 (0.035)**	1.359
Irrigation rate							
Tribe2017	−0.014 (0.072)	0.038 (0.068)	0.045 (0.066)	0.046 (0.064)	0.021 (0.064)	0.033 (0.066)	1.535
Sprinkle-irrigation rate							
Tribe2017	−0.294 (0.068)***	−0.297 (0.063)***	−0.322 (0.062)***	−0.323 (0.061)***	−0.338 (0.062)***	−0.326 (0.065)***	1.295
High-value cropland rate (CDL)							
Tribe2017	−0.102 (0.034)***	−0.103 (0.031)***	−0.106 (0.030)***	−0.108 (0.029)***	−0.092 (0.029)***	−0.088 (0.027)***	1.676
High-value cropland rate (WRL)							
Tribe2017	−0.055 (0.019)***	−0.051 (0.017)***	−0.045 (0.016)***	−0.043 (0.015)***	−0.034 (0.015)**	−0.032 (0.015)**	1.607

Notes: The second order local polynomial fuzzy RD regression results for six dependent variables. Five different fixed bandwidth choice results are listed, including an optimal bandwidth choice calculated based on Calonico, Cattaneo, and Titiunik (2014). All regressions include controls for climate, elevation, soil productivity, distance to river, and township fixed effects. Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Standard errors constructed using a heteroscedasticity-robust nearest neighbor variance estimator are shown in parentheses.

Discussion and Conclusion

This paper explores how investment and production on agricultural land in Indian country might be negatively affected by the limitations and restrictions caused by tribal trust status. Our economic framework suggests fee-simple landowners with secure property rights may more readily obtain access to commercial credit and borrow money to invest in capital intensive sprinkler irrigation systems. The effect is that Uintah reservation lands see less intensive cultivation and lower value crops. Our findings illustrate that when controlling for land quality, climate, and geographic location, fee-simple land has irrigation rates similar to tribal trust land. Conditional on being irrigated, tribal land is around thirty-two percentage points less likely to be sprinkler irrigated today. Moreover, fee-simple farms have higher levels of high-value crops.

Although our results are consistent with a story of tribal trust status hindering agricultural development, our observed outcomes are likely affected by a number of different channels. Trust status may prevent the enforcement of contracts on reservations through state courts, which makes lending to farmers on tribal trust land riskier (Anderson and Lueck 1992). Because much agricultural land in the US is leased, the limitations the federal government places on the length of lease terms will affect land use decisions (Shoemaker 2006). Whether trying to borrow capital or lease land, the hurdles in dealing with the bureaucracy of the federal government, in this case the BIA, can lead to substantial delays (ILTF 2003), which are potentially costly and reduce production and investment (Edwards, O'Grady, and Jenkins 2019). Parsing the different channels through which irrigation investment or high-value crop production might be reduced by trust status is beyond the scope of this paper.

An additional channel that might exacerbate the effect of trust ownership is sorting on operator skill. We do not believe this type of sorting is problematic, as it is largely a consequence of institutions. Fee simple land can be sold or leased to the best operators, who may refrain from leasing tribal trust land due to difficulties in investing in the land or even acquiring a lease. Skilled operators would likely be more willing to grow high-value crops as well as to invest in more sophisticated tools like sprinkler irrigation systems. Because this type of sorting will occur due to trust ownership, it is important to interpret our results as inclusive of this effect.

Another potential issue, similar to the problem of sorting, is that of overall land use choice. Because the Uintah tribe and federal government manage tribal trust land, they can make broad land use choices that differ from fee-simple landowners and that are not directly related to tribal trust status. One such choice, discussed earlier, is the designation of the northern contiguous land block as grazing land. But other land use decisions may also impact these choices. The Uintah Reservation and surrounding areas are located in a region rich in oil and natural gas. The decision to drill reduces land available to agriculture and may change the incentives of landowners. However, land use choices are unlikely to be the cause of our main findings on crop choice and irrigation type. Our measure of high-value crops is compared across land known to be in agricultural use; the irrigation type measure is compared only to land known to be in irrigation. Unlike the decision to designate grazing land, which is highly correlated with the allotment boundary and which we test directly in the appendix B in the supplementary material appendix S1, there is no reason to believe that potential energy production is correlated with the allotment boundary, which occurred prior to the discovery of the region's oil and gas deposits.

There are additional alternative channels that could affect agricultural investment and production on tribal land that may not be directly related to trust status. One example is reservation access to federal irrigation projects. In 2006, the General Accounting Office criticized the operation of the sixteen BIA irrigation projects due to deferred maintenance, a lack of managerial expertise in water systems, and uncertainty over financial sustainability. Because irrigation management is not a priority for BIA, the report concludes that it might be beneficial if an agency like the Bureau of Reclamation, which provides water for non-tribal farmers, managed these projects (GAO 2006, p. 28). The non-tribal federal water projects in central Utah have been completed, but tribal projects have lagged (DOI 2018, 5.1–8). However, at least for the areas immediately adjacent to allotment boundaries, both trust and fee-simple farmers are served by the Uintah Indian Irrigation Project, suggesting this is not a key driver of our estimated results. Alternative suppliers of water in the region include private irrigation companies, which operate on the periphery of the reservation, and although they do supply some water to tribal irrigators, they are primarily utilized by fee-simple landowners (DOI 2018, 5.1–13). The extent to which this affects our estimated results or their interpretation is unclear. Trust land appears to have similar access and levels of irrigation, suggesting water supply is not the key issue in irrigation investment. Although private irrigation companies may be able to provide higher quality delivery infrastructure, the lack of tribal access to these systems may be related to their trust status and inability to secure capital.

There are also alternative explanations for the issues Indian farmers have faced in acquiring capital. Evidence suggests that the USDA systematically discriminated against Indian farmers by denying them credit they routinely offered to white farmers under the USDA Farm Loan Program. A class-action lawsuit encompassing the period 1981–1999 (Keepseagle v. Vilsack) was settled in 2010 with a $760 million payment to affected Indian farmers. USDA has traditionally been the largest single lender to Indian farmers and ranchers (Shoemaker 2006, p. 22). Discrimination in access to credit would affect trust land, which is more likely to be farmed by Indian farmers than fee-simple land, without directly relying on trust ownership as an explanation. However, it is unclear whether this channel is fully independent of trust status, which may have in part affected the USDA loan-making decisions. Tribes have also argued that crop insurance products offered by USDA are not well-suited for the agricultural practices of tribal farmers and that tribal farms may not qualify for federal disaster assistance. These channels could potentially affect irrigation investment and high-value cropping decisions, but our framework does not allow us to test their importance directly.

Finally, it is worth noting that the paper focused on tribal trust ownership, which is not the same as communal ownership. We make no claim about the benefits of private land ownership (fee simple) relative to communal ownership. Leonard, Parker, and Anderson (2020) show that per capita income is higher both on reservations with high levels of communal land and with high levels of fee-simple land. What may be problematic is the fractionation of land, which is the extent to which land types are mixed. Portions of the Uintah Reservation are fractionated, providing a partial alternative explanation for different outcomes. Fractionated land has been shown to negatively affect oil and gas production on reservation lands (Leonard and Parker 2018) and negatively affect irrigation investment and development, although not in the context of a reservation (Alston and Smith 2019).

We conclude that agricultural development on the Uintah reservation is suppressed relative to non-reservation land. This lack of investment is consistent with our expectation of the effect of tribal trust land on access to capital through a variety of channels. Differentiating between these channels is beyond the scope of this paper. In addition, there are several alternative explanations to our main findings that will require additional research to disentangle from the effect of tribal trust ownership. Although lack of investment may have multiple causes, it appears clear that improving access to capital, so tribal farmers can invest in irrigation systems at the level of their fee-simple neighbors, is key to improving lagging agricultural development on reservations in the American West. More research is needed to understand the effectiveness of program and policy changes designed to increase access to capital for agriculture on reservations.

Supplementary Material

Supplementary material are available at *American Journal of Agricultural Economics* online.

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