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Land Ownership and Irrigation on American Indian Reservations

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Abstract

American Indian reservations are often characterized by low income and high rates of poverty relative to adjacent non-reservation land. To understand the role institutions governing land ownership play in these outcomes, we examine agricultural land use and irrigation on parcels on and adjacent to the Uintah-Ouray Indian Reservation in eastern Utah. Land within the reservation is held in trust by the federal government and has significant restrictions on its use and development. We predict that this land will see lower investment in irrigation and therefore lower agricultural productivity. We use the exogenous allocation boundaries of a 1905 land allotment as a natural experiment, employing both a sharp and a fuzzy regression discontinuity (RD) design to explore how land ownership has affected agricultural land use, irrigation levels, and irrigation investment. Our results suggest that the original allocations provided land of similar quality across the border. Despite this, tribal lands are around 18 percentage points less likely to be irrigated today, and conditional on being irrigated, tribal land has a 31 percentage point lower rate of capital-intensive sprinkler irrigation. Tribal land is also less likely to grow high-value crops. These results suggest that trust ownership creates significant barriers to the acquisition of capital for agricultural investment, and helps explain lagging agricultural development on reservations.

Keywords: Regression Discontinuity; Indian Reservation; Property Rights; Agriculture; Irrigation

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1. Introduction

The link between insecure property rights and poverty on American Indian reservations has drawn significant attention in recent years. The median household income for American Indian communities in 2016 was $38,502 while the estimate of the U.S. as a whole was $55,322.[2] This divergence is even more pronounced in terms of agricultural production. In 2007 the average American Indian farm saw sales of $40,331, less than 1/3 of the US average (Census of Agriculture 2012). Previous studies have traced the underlying causes for limited tribal development to weak institutions as a result of both tribal and federal policies (Anderson and Lueck 1992; Cornell and Kalt 2000; Anderson and Parker 2008). We extend this literature to an analysis of agricultural irrigation. With 75% of land in Indian country dedicated to agriculture, understanding how institutions affect the productivity is key to improving economic development on reservations (Shoemaker 2006, p. 11).

In this paper, we use the case of the Uintah and Ouray (Uintah) Reservation in eastern Utah to explore how institutions have affected the pattern of agricultural development. The Uintah Reservation is the second largest by area in the United States and, like many reservations, its current area has been reduced significantly over time. Important to this paper, the tribe was ultimately allotted a few contiguous blocks of land in 1905 via the Dawes Act, with the remaining portions of the reservation opened to white settlement. Within this allocation, some land was claimed as fee-simple by tribal members while the unclaimed land reverted to tribal control as federal trust land in 1937. Fee-simple owners have complete property rights and can freely sell or lease the land. In contrast, tribal land sales are restricted and require the review of both the tribal government and the Bureau of Indian Affairs (BIA). Throughout the paper we

[2] U.S. Census Bureau, 2012-2016 American Community Survey 5-Year Estimates.

define tribal land as any land or interest in land owned by a tribe or tribes, title to which is held in trust by the United States or is subject to a restriction against alienation under the laws of the United States.[3] The lack of land use flexibility and the inability of lenders to enforce contracts on reservations results in a lack of access to commercial credit, limiting the opportunities to borrow money for capital-intensive improvements (Anderson and Lueck 1992).

In this study, we apply a spatial regression discontinuity (RD) approach to identify the effect of tribal ownership on agricultural development. Specifically, we utilize the straight-line boundary of the 1905 allocation, both directly and as an instrument on current land ownership, to identify the effect of trust ownership on irrigation and irrigation investment. Land ownership changed discretely at the straight-line boundary in 1905 at the time of allocation. On one side, all the lands were under tribal trust, while on the other side, all the lands were fee-simple. The spatial RD approach has been widely applied to 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), but to our knowledge has not been used to examine trust land ownership.

We develop a new dataset by linking agricultural irrigation choice, land ownership data, and historic land allocation. We implement a sharp RD approach with local polynomial regression to examine the impacts of current agricultural choices across the 1905 allotment boundary. However, since 1905 some land has changed hands, so the assignment of the treatment today may be based on additional variables that are unobserved. Selection into treatment is dependent on both observable and unobservable factors, and we therefore expect the boundary of 2017 land ownership to be a "fuzzy" rather than "sharp" discontinuity. To address

[3] Definition is from Tribal Energy Resource Agreement (TERAs).

this issue we utilize a sharp RD design on the 1905 boundary excluding all lands which have switched ownership, and then implement a fuzzy RD design. This approach treats 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.

We find that tribal lands have irrigation rates around eighteen percentage points lower under the instrumented 2017 tribal land ownership. Further, tribal lands see significantly less investment in capital-intensive irrigation systems, with irrigated tribal land seeing 31 percentage point lower rates of sprinkler irrigation. Tribal land is also less likely to grow high-value crops. On the lands that did not change hands, the sharp RD results show that tribal lands have 13 percentage points less investment in sprinkler irrigation systems, and are less likely to grow high-value crops. These results suggest that tribal trust ownership inhibits agricultural production and irrigation investment on the reservation. While there is anecdotal evidence the difficulties are related to insecure land tenure, we also discuss several alterative explanations for the underinvestment in tribal agriculture.

The paper proceeds as follows: section two provides background on tribal land allocation and the Uintah Reservation. Section three describes an economic framework for the effect of insecure land tenure and provides predictions. Section four provides details on the empirical design and econometric approach. The econometric results are provided in section five and section six concludes.

2. Background

2.1 Reservation Land Ownership

American Indian Reservations were formed from territory controlled by the United States government to provide an area of settlement for previously autonomous tribes. Initially, reservation allocations were to tribes, but as land pressure increased, the US congress in 1887 passed the Dawes Act which allowed the government to allocate land within the reservations to individuals. Reservation areas had portions reserved for allocation to tribal members and the remaining land was opened for white settlement. In the allocated areas, individual tribal members could make a claim to own land individually. The 1934 Indian Reorganization Act again changed the rules and the unclaimed allotment areas reverted to tribal control. The Act resulted in the three categories of land ownership we see on reservations today: fee-simple, land which is privately owned; tribal trust, land allocated to tribes under the Dawes Act but which was never claimed by tribal members and reverted to tribal control; and individual trust, which is allocated land that was claimed by individuals but for which the process of transitioning to fee-simple was never completed.

Trust land has significantly different constraints on land trade and alienation, relative to fee-simple. While the owner of the private land can freely sell or lease the land, tribal trust land is owned by the federal government and managed jointly by tribal governmental organizations and the Bureau of Indian Affairs (BIA). BIA maintains ownership records and manages almost any 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 measure the view of Indian peoples 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) found that trust land constraints imposed by the federal government significantly reduced the value of agricultural output on reservation land.

Individual or tribal trust land may be mortgaged with the consent of the landowners and the BIA. However, many private commercial lending difficulties exist on trust lands. First, individuals seldom own direct title and therefore do not have collateral. Second, it is nearly impossible to get title insurance on Indian 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.[4]

2.2 Indian Agriculture

The potential for jurisdictional uncertainty creates complexity and reduces access to credit for Indian farmers and ranchers. Even though the tribe functions as a sovereign entity according to the governing by-laws, the U.S. Secretary of Interior has final authority over many tribal actions. Agricultural land leases are an example. Agricultural leases may be negotiated directly with the landowner, often 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, 13). Leases are codified as having a maximum duration of 10 years, unless substantial investment is required, in which case 25-year leases are possible (25 U.S.C. § 3715(a)(1)).

Indian farmers have faced difficulties and discrimination in accessing USDA loans. Evidence suggests that the USDA systematically discriminated against Indian farmers by

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

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 is one potential explanation for lagging agricultural development. 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.[5]

Another potential limit to the development of irrigated agriculture on tribal land is problematic access to federal irrigation projects. Reservations are primarily located in arid regions, and the BIA operates 16 irrigation projects. In 2006, the General Accounting Office criticized the operation of these 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).

2.3 Uintah and Ouray Reservation

The Uintah 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 started the process by which significant portions of the reservation were reallocated to private individuals. Six years later Congress passed another Indian Appropriations Act and set a timeline for the BIA to acquire an agreement with the tribe on their land allotment. The reservation was

[5] https://www.tribalselfgov.org/wp-content/uploads/2018/03/Farm-Bill.pdf; http://www.ncai.org/NFBC_Policy_Recommendations.pdf.

allotted in 1905 and entry by settlers onto the unreserved and unallotted lands occurred after that time. Under the allotment policy, adult members of the Uintah tribe received allotment lands between 40 and 640 acres, depending on the suitability of the land for farming. This property was subject to a 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 both Indian and non-Indian farmers in the area. 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). In 1937, under the 1934 Indian Reorganization Act, all tribal lands that had not been privatized reverted to Uintah control. Today, this land is held in tribal 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 contributors to Uinta 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)."

Today, the Uintah reservation is the second-largest US Indian reservation in land area. Figure 1 shows the allocation of land within the reservation. Federal lands located around the northern and western boundaries of the Uintah and Ouray Indian reservation are primarily national forest in the Uintah Mountains. In the agricultural areas, tribal trust and private fee-simple land are the primary ownership types. Uintah tribal bylaws limit land leases to a period of five years, although exceptions may be made for irrigable land.[6]

The area around the Uintah Reservation is arid, with the agricultural areas receiving approximately 270mm of precipitation per year. There are thirty-two different crops grown in the area, but the majority of acreage is in alfalfa. The average irrigation rate within two miles of the tribal boundary is around 39.7% on fee-simple land versus 22.8% on tribal land. Within the two-mile window, only 7.3% of irrigated tribal land uses sprinkler irrigation, compared to 31.2% of private irrigated land. We now turn to an analytic framework to demonstrate how insecure property right institutions could cause tribal lands to differ in their investment in irrigation.

3. Economic Framework and Predictions

Previous research on property rights and investment (Demsetz 1967; Besley 1995; Anderson and Parker 2008) suggests there are multiple channels through which land property rights affect agricultural investment. We adapt Besley's (1995) model to our case.

Consider a farmer who invests c amount of capital in his farm. The revenue function of investment can be written as $R(c, x)$ where x represents land property rights now and in the future; x increases as the land property rights become stronger. $R(\cdot)$ is assumed to be an increasing function of c and x, and concave in c. $C(c, x)$ represents the cost of investment and it is an increasing function of c and non-increasing function of x. The optimal investment choice is then given by:

$$\max_{c} I(c, x) = R(c, x) - C(c, x) \tag{1}$$

The first order condition for the choice of capital investment, c, is:

$$I_1(c, x) = 0 \tag{2}$$

[6] Constitution and By-Laws of the Ute Indian Tribe of the Uintah and Ouray Reservation Article VI(1)(c).

Taking the total derivative of the first order condition in equation (2), we get:

$$\frac{\partial c}{\partial x} = -\frac{I_{12}(c,x)}{I_{11}(c,x)} \tag{3}$$

Because of the concavity of the investment function, $I(\cdot)$, the maximum point exists if $I_{11} < 0$. Importantly, if $I_{12} > 0$, it implies a positive relationship between agricultural investment and land property rights. We will discuss how land property rights could affect agricultural investment through three different channels.

The first channel is freedom from expropriation (Demsetz 1967; Alchian and Demsetz 1973). That is, a farmer does not have incentive to invest if his land if it could easily be seized by others. Suppose the probability of losing farmland in the future is $p(x)$, where $p(x)$ is between zero and one, and decreases as property rights increase. The direct return from farming is defined as $R_p(c)$. Then, the maximization of the expected return for the farmer is:

$$\max_c R(c,x) = \left(1 - p(x)\right) \times R_p(c) + p(x) \times 0 \tag{4}$$

$R_{12}(c,x)$ can be calculated by taking the derivative of $R_1(c,x)$ with respect to x:

$$R_1(c,x) = R_p'(c) - p(x) \times R_p'(c) \tag{5}$$

$$R_{12}(c,x) = -p'(x) \times R_p'(c) > 0 \tag{6}$$

Since $I_{12}(c,x) = R_{12}(c,x) - C_{12}(c,x)$ and $C(c,x)$ is a non-increasing function of x by assumption, it is straightforward to conclude that $I_{12}(c,x) > 0$.

The second channel is using land as collateral: secure land property rights reduce the interest rate. Lower interest rates increase land investment because the interest rate is equal to the required marginal productivity of capital investment (Feder and Feeny 1991; Besley 1995). Suppose a farmer would like to borrow money from a lender to invest in a sprinkler system. We assume the initial wealth of the farmer is 0. The money borrowed from the lender is defined as b. The lender charges an interest rate of $r(x)$. We assume that interest rate is negatively correlated with the land property rights, $\frac{\partial r(x)}{\partial x} < 0$. The probability of earning the return is q. The physical return from the new sprinkler system is $R_p(c)$, $R_p{}'(\cdot) > 0$ and $R_p''(\cdot) < 0$. The utility function $u(\cdot)$ is a smooth, concave and increasing function. Thus, the farmer's expected utility function can be written as:

$$I\ (c, x) = \max_{\{b,c\}} \{u(b - c) + qu\big(R_p(c) - r(x) \times b\big) + (1 - q) \times 0\} \tag{7}$$

The first order condition with respect to the choice variables $\{b, c\}$ can be specified as:

$$-u'(b - c) + qu'\big(R_p(c) - r(x) \times b\big) \times R_p{}'(c) = 0 \tag{8}$$

$$u'(b - c) + qu'\big(R_p(c) - r(x) \times b\big) \times -r(x) = 0 \tag{9}$$

It is straightforward to show that:

$$R_p{}'(c) = r(x) \tag{10}$$

The first order condition for the choice of c, after the envelope theorem is used for the choice of b, can be written as:

$$I_1(c, x) = R_p{}'(c) - r(x) \tag{11}$$

Solving equation (10) and (11) simultaneously, we obtain:

$$I_{12}(c, x) = -\frac{\partial r(x)}{\partial x} \tag{12}$$

Equation (10) implies that at the maximum utility, the marginal productivity of capital invested on an Indian farmland is equal to the interest rate charged from a lender. Since we assume a negative relationship between land property rights and interest rate, $\frac{\partial r(x)}{\partial x} < 0$, we can conclude that $I_{12}(c, x) > 0$.

The third channel comes from the intuition that better transfer rights reduce the land transfer cost and increase investment incentives. We assume that the trading cost is dependent on a farmer's transfer rights. Suppose the sale price of the land is p. If the farmer sells the land, the best offer available is w, which has the density function of $g(w)$, $w \in [\underline{w}, \overline{w}]$. If the Indian farmer decides to use the land, his payoff is δc, where c is his return to investment and δ is the marginal product of capital, which has the density function of $f(\delta), \delta \in [\underline{\delta}, \overline{\delta}]$. The trading cost, defined as $\pi(x)c$, is a decreasing function of x, and $\pi'(x)$ is less than zero. Then, the optimal land price under a Nash bargaining solution is:

$$\max_{p}(p - \pi c - \delta c)\,(wc - p) \tag{13}$$

Solving equation (13), we get the optimal land price, $p^* = \frac{\pi+\delta+w}{2}c$. Hence, the farmer's payoff from selling his farmland is $p^* - \pi c = \frac{\delta+w-\pi}{2}c$, and that from not selling the farmland is δc. Consequently, the farmer's expected return is:

$$R(c, x) = cE(max\{\frac{\delta+w-\pi}{2}, \delta\}) \tag{14}$$

Differentiating equation (14) with respect to c, we obtain:

$$\begin{aligned} R_1(c, x) &= E(\max\{\frac{\delta + w - \pi}{2}, \delta\}) \\ &= \int_{\underline{w}}^{\overline{w}} \left[\int_{\underline{\delta}}^{w-\pi(x)} \frac{\delta + w - \pi(x)}{2} f(\delta)\, d\delta + \int_{w-\pi(x)}^{\overline{\delta}} \delta f(\delta)\, d\delta \right] g(w) dw \end{aligned} \tag{15}$$

Further differentiating equation (15) with respect to x yields:

$$R_{12}(c, x) = -\left[\int_{\underline{w}}^{\overline{w}} F\big(w - \pi(x)\big) g(w) dw \right] \pi'(x) \tag{16}$$

Because land property rights are negatively correlated with land transfer cost, that is $\pi'(x) > 0$, we get $R_{12}(c, x) > 0$ and $I_{12}(c, x) > 0$.

Uncertainty from expropriation, insufficient collateral, and high land transfer costs contribute to insecure land property rights which, in turn, suppress agricultural investment. In the subsequent empirical analysis, we focus on whether this prediction holds for investment in irrigation capital. Capital is required to construct irrigation works, purchase pumps, pipes, and other equipment, as well as to prepare a field to receive water. Both flood and sprinkler irrigation requires capital expenditure, although the investment cost of flood irrigation is significantly lower than sprinkler systems, such as center pivot systems (Dumler et al 2011). Importantly, a more-efficient sprinkler system increases yields and allows for more acres to be irrigated (Dumler et al 2011). Irrigation, and particularly sprinkler irrigation, increases a farmer's ability to grow high-value crops. Therefore, on two otherwise identical parcels, we expect: (1) less investment in irrigation technology on tribal land; (2) conditional on irrigation, we expect less investment in sprinkler irrigation on tribal land; and (3) we expect lower value crops to be grown on tribal land. The next section lays out our empirical methodology for testing these predictions.

4. Empirical Framework

4.1 Data Construction

Variables on land use, land ownership, land quality and climate are constructed for the Uintah-Ouray Indian Reservation. Table 1 shows summary statistics and data construction formulae. Our unit of observation is the parcel from cadastral survey records housed by the Bureau of Land Management (BLM) and supplemented with local records and geographic control coordinates obtained from states, counties, and the United States Geological Survey (USGS) and the United States Forest Service (USFS). Parcels are generally around 40 acres. The survey typically divides land into 6-mile-square townships and townships are subdivided into 36 one-mile-square sections. Sections can be further subdivided into quarter sections, quarter-quarter sections, or irregular government lots.[7] We include the township as a control variable to

[7] https://nationalmap.gov/small_scale/a_plss.html

make sure that we only compare the adjacent parcels. Land ownership type is assigned to each parcel using Geographic Information System (GIS) measurement. The land ownership data comes from the State Geographic Information Database (SGID). This data set contains current surface land ownership administration and designation categories as of 2017. The 2017 tribal land boundary is extracted from this data set. The 1905 allotment boundary is digitized from the Uintah Indian Reservation Disposition map created in 1905. This disposition map contains historical land allotment details at the parcel level for the Uintah reservation. Distance to the boundary is calculated as the shortest distance from the border of each parcel to the 1905 and 2017 boundaries using GIS. We then link the public land survey system (PLSS) quarter, quarter section (parcel) land ownership in 1905 and 2017 to a soil productivity index (PI) grid.

A. Soil Productivity Data

We obtain the soil PI grid raster map from Iowa State University Geospatial Laboratory for Soil Information. The PI is an ordinal measure of soil productivity, which ranges from 0 (least productive) to 19 (most productive), based on soil taxonomy information (Schaetzl et al. 2012). Since the index is ordinal and some parcels contain two different soil productivity indices, we cannot calculate the mean soil productivity of each parcel as a continuous variable. Following Schaetzl et al. (2012), we assign different soil productivity ranks to each PLSS parcel to ensure each parcel has a unique soil productivity rank. If one parcel has two different soil productivity ranks, we divide this parcel into two parcels with unique rank.

The mean elevation of each parcel in the baseline map is calculated via GIS. The elevation data is obtained from the NASA Shuttle Radar Topographic Mission (SRTM) 90m Digital Elevation Dataset. The SRTM provides digital elevation data (DEMs) for over 80% of the globe and the resolution of the dataset is 3 arc-seconds (approximately 90m resolution).

B. Agricultural Data

We construct our parcel-level agricultural data using the agricultural land use percentage within each parcel. First, we calculate the agricultural rate using cropland data from CropScape-Cropland Data Layer (CDL) [8] in the year 2015. 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. The CDL database covers the entire Uintah reservation. We obtain 9,304 parcels of 40 acres from CDL cropland classification. The average agricultural rate was approximately 30% in the Uintah region. The second database we use is the Water Related Land Use (WRL) data set published annually by the Utah Division of Water Resources.[9] This database provides more accurate agricultural and non-agricultural land cover on portions of the Uintah reservation, but it does not cover the entire study region. The total number of observations is 8,178 parcels, with a 60% agricultural rate. We test the agricultural rate across the boundary using both the CDL and WRL datasets and compare the results.

C. Irrigation Data

Irrigation rate and sprinkler irrigation rate data come from the WRL data for the year 2012. There are two primary irrigation methods used in the region, sprinkler and flood. Because drip-irrigated acreage is small, its effect on our empirical results is inconsequential and is thus dropped from the analysis of irrigation. Parcel level irrigation and sprinkler irrigation rates are captured by overlaying the irrigation map and sprinkler map on our baseline map. We obtain the

[8] CropScape dataset is hosted by National Agricultural Statistics Service, United State Department of Agriculture. Agricultural land layer is in year 2015. Website: *https://nassgeodata.gmu.edu/CropScape/*

[9] Final water related land use data describing agricultural related land use in the Uintah region are between 2011 and 2016. The survey year of Uintah region is Year 2012. The last update of this dataset is August 3, 2017.

sprinkler irrigation rate by dividing the sprinkler irrigated land by total irrigated land. The formulas to calculate the irrigation rate and sprinkler irrigation rate can be found in Table 1.

Figure 2 shows irrigation by type in the Uintah study region. The left panel shows the correspondence between WRL parcels and the 1905 allotment boundary, and right panel shows the correspondence with the 2017 land ownership. The solid black line indicates the 1905 allotment boundary on the left, and the 2017 tribal land boundary on the right.

D. High-value Crops Rate Data

We obtain crop data used in this study from the CDL and WRL data. We divide the crops grown in the Uintah reservation into two groups: (i) high-value crops, such as corn and beans, and (ii) low-value crops, such as alfalfa (See Table A1 for crop value classification). Table 1 shows that more high-value crops are grown on average on private land than tribal land in both data sets.

Figure 3 demonstrates the crop value distribution on tribal and private land in the Uintah reservation using WRL data set. The left panel provides the distribution using 1905 allotment boundary, while the right panel is for the 2017 tribal land boundary. In both panels, it appears that more low value crops are inside the tribal boundary.

E. Climate Data

Temperature and precipitation raster datasets were collected from WorldClim1.4: Current condition (~1960-1990). The raster dataset provides the average value of climate statistics between year 1960 and 1990. The resolution of the raster datasets is 30 arc-seconds (~1km). We obtain three temperature indicators, including annual mean temperature, maximum temperature of the warmest month, and minimum temperature of the coldest month. In addition, we include precipitation indicators, such as annual precipitation, to control for differences in agricultural productivity across the reservation boundary.

4.2 Regression Discontinuity Design

We adopt a spatial regression discontinuity (RD) design to study the cross-border variation in agriculture in the Uintah region. The spatial RD approach has been broadly implemented in different contexts in recent years to study intervention or treatment effects (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). Our first empirical strategy exploits the exogenous allocation boundary of 1905 land allotment to explore the impacts of historical tribal land allotment on recent agricultural activities in the context of a sharp RD design.

The sharp RD approach used in this paper hinges on two identifying assumptions. First, the local randomization assumption requires that within a bandwidth of pre-specified 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 examine the climate statistics, land, and soil variables inside and outside of the 1905 allotment boundary.

Table 2 presents the balance test of climate, land, and soil variables for five bandwidth choices (0.5, 0.75, 1, 1.25, 1.5 miles) around the 1905 allotment boundary. In particular, the Welch t-test with log transformation and nonparametric Wilcoxon test are used to test for the difference in means between tribal and private land. The Welch t-test statistics are reported in parentheses, while the Wilcoxon test statistics are in brackets. In the first three columns, the sample includes only parcels located within less than 0.5 miles from the 1905 allotment boundary, and this threshold is gradually increased to 0.75, 1, 1.25, and 1.5 miles in the succeeding columns. It is apparent that the annual mean temperature, annual precipitation, and precipitation of driest month are statistically identical within 1 mile (0.5, 0.75, 1 mile bandwidths) distance across the boundary. As the distance from the boundary increases (1.25 and 1.5 mile bandwidths), however, the values of the balance test variables become statistically different across the boundary. This is consistent with the identification of the treatment effect under RD design. The eighth row shows small statistically significant differences in elevation. The elevation differences are due in part to the location of the Uintah reservation, which is surrounded by a mountain range. The soil productivity is identical within small bandwidths (0.75, 1, 1.25 mile bandwidths).

The second identifying assumption of sharp RD 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 variable. He argued that if observations are able to sort themselves across a given bandwidth, the observations just to the left of the cut-off are likely to be substantially different from those to the right. In contrast, De La Cuesta and Imai (2016) argued that the local randomization assumption is stronger than the continuity assumption, and nothing in the continuity assumption requires the expected potential outcomes on both sides of the threshold to be identical. That means imbalance in pretreatment covariates just below and above the cut-off does not necessarily imply the violation of the identification assumption for a valid RD design.

Under the spatial RD setting the selective sorting assumption would, however, be violated if a direct 1905 allotment effect triggered significant out-migration of relatively highly irrigated land parcels, leading to a larger indirect effect. However, because American Indian Reservations were initially enacted for the express purpose of allowing the tribal members to utilize the land for agricultural production, the continuity assumption is unlikely to hold. For this reason, we recognize the possibility of land switching around the discontinuity and build our models to identify treatment effects under these conditions. Because tribal land boundaries have changed since 1905, we first apply our sharp RD approach only on the lands that do not change ownership to examine the impacts of current agricultural choices across the 1905 allotment boundary. These lands are not affected by the land transactions since 1905 and for this reason retain random assignment. Table 3 presents the balance test for the 1905 tribal land boundary with the lands that do not change ownership. The results for lands that never change hands (Table 3) are similar to those from Table 2. Specifically, the parcels adjacent to the 1905 allotment boundary tend to be similar in reasonable characteristics within smaller distance for the boundary. However, they are different as further distances. Some of the observed differences between Table 2 and 3 can be explained by the fact that fewer tribal parcels are selected in land dataset that never change hands.

Our second empirical strategy utilizes a fuzzy RD design, which allows us to explore the impact of recent tribal land ownership on agricultural investment today. In the fuzzy RD design, instead of using the lands that do not change ownership, we use all the parcels located within the designated bandwidth of the 2017 boundary. The right panel of Figure 1 illustrates the land ownership changes between 1905 and 2017. Green areas represent the land held by the tribe in both 1905 and 2017; red areas represent the land that was allocated to the tribe and became fee-simple between 1905 and 2017; grey areas represent the land not allotted to the tribe and opened for settlement in 1905; and blue areas represent land that was not originally allocated and was transferred back to the tribe after 1905. It is evident that most of the land returned to the tribe is located on the periphery of tribal land, while most of the land sold to private owners is intermingled with the tribal land. This checkerboard pattern of tribal and private land causes considerable fragmentation of the tribal boundary today.

Table 4 presents the balance test across the 2017 tribal land boundary. It is clear that all the climate and land variables are statistically different across the 2017 boundary. This is the result of tribal landowners selling land to non-tribal members (recall that more than 30,000 acres of Uintah agricultural land were sold or leased to non-Indian neighbors (Duncan 2000, p.207)), which considerably altered the original 1905 allotment boundary. Climate and land quality have likely affected whether a parcel has changed ownership since 1905. Consequently, these transactions cause fuzziness in our sample along the 2017 boundary, and we address this by applying a fuzzy RD design, using 1905 allotment boundary as an instrument for current land ownership.

A. Empirical framework for the 1905 allotment boundary

The 1905 allotment boundary treatment is a straight-line discontinuous function. Thus, we implement a sharp RD design to examine the impact of tribal trust ownership on the agricultural rate, irrigation rate, sprinkler-irrigation rate, and high-value crops rate across the 1905 allotment boundary. For simplicity, we name the treatment in the sharp RD model *Allotment1905*, 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. $dist1905_i$ is the running variable, representing shortest distance of parcel i from the 1905 allotment boundary

($\overline{dist1905}$). $\overline{dist1905}$ is the threshold value (boundary position), equal to 0 in this model. Since the assignment to treatment is sharply determined by the 1905 allotment boundary, the relationship between the treatment indicator and the running variable $dist$ is established by

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

The parametric linear RD model with a control for distance from the cutoff is:

$$\begin{aligned} R1905_i = {} & \alpha + \beta_1 Allotment1905_i + \beta_2 f\left(dist1905_i - \overline{dist1905}\right) \\ & + \beta_3 f\left(dist1905_i - \overline{dist1905}\right) \times Allotment1905_i + X'\varphi + \varepsilon_i \end{aligned} \tag{17}$$

where $R1905_i$ is the outcome variable of interest of parcel i within x-miles distance from either side of the boundary. X is a vector of controls that includes soil productivity, township and elevation. In our model, we test four different outcome variables: agricultural rate, irrigation rate, sprinkler-irrigation rate, and high-value crop rate. $f(\cdot)$ is a polynomial distance function and ε_i is an error term with standard properties. The parameter of interest is β_1, which captures the treatment effect.

As long as a parcel is near the cutoff, $\overline{dist1905}$, the treatment effect of *Allotment1905* is valid. Hence, an estimate of average treatment effect can be obtained by comparing average $R1905_i$ of those just above and those just below $\overline{dist1905}$. However, the bandwidth has to be large enough to encompass sufficient observations to get a reasonable amount of precision in the estimated average value of $R1905_i$. A larger bandwidth yields more precision but potentially introduces bias.

B. Empirical framework for the 2017 tribal land ownership

To understand the difference in irrigation rates across the current land ownership boundary, we utilize a fuzzy regression discontinuity. The relationship between land ownership today ($Uintah2017_i$) and the running variable $dist2017_i$ is established by:

$$Uintah2017_i = \begin{cases} 1 \quad if \quad dist2017_i \geq \overline{dist2017} = 0 \\ 0 \quad if \quad dist2017_i < \overline{dist2017} = 0 \end{cases}$$

We cannot compare the average treatment effect immediately above and below the 2017 boundary because the average treatment effect around the cut-off will understate the causal effect. Instead, we can adopt $Allotment1905$ from the sharp RD specification above as an instrumental variable.

There are two basic assumptions about the instrumental variable. 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 boundary is strongly related to the 1905 allotment boundary. Second, the exclusion condition: $Allotment1905_i$ has to be unrelated to $R2017_i$, conditional on $Uintah2017_i$ and other controls such as climate and land quality. While 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. Because the irrigation project delivered water to both tribal and non-tribal lands, it is also not the case that these boundaries were subsequently used to determine irrigation access. Moreover, the balance tests across the 1905 allotment boundary do not indicate substantial differences in land and climate characteristics that might have been observable at the time of assignment (see Table 2).

The fuzzy RD design is a two-stage estimation process. The first stage involves regressing the 2017 treatment indicator on the 1905 boundary and additional controls (soil productivity, township and elevation):

$$Uintah2017_i = \lambda + \gamma Allotment1905_i + g\left(dist1905_i - \overline{dist1905}\right) + X'\varphi + \nu_i \tag{18}$$

To estimate the first stage we fit a generalized linear model with a probit function. Once we obtain the fitted value of $Uintah2017_i$ from stage 1, we use $\widehat{Uintah2}017_i$ to evaluate the average treatment effect in stage 2:

$$R2017_i = \delta + \beta_1 \widehat{Uintah2}017_i + h\left(dist1905_i - \overline{dist1905}\right) + X'\varphi + \varepsilon_i \tag{19}$$

The treatment effect is captured by β_1.

C. Bandwidth and functional form selection

Identification of the local spatial RD treatment effect requires data points in the immediate neighborhood around the border, whether it is a sharp or fuzzy design. 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 and variations in other variables across the discontinuity may affect the estimates. While some of these effects can be controlled using additional regressors and polynomial order trends in distance, the selection of the bandwidth around the discontinuity remains an important consideration. In the present study, we use a bandwidth selection procedure based on Calonico, Cattaneo, and Titiunik (2014, 2015), who suggest using a simple kernel and then verifying the robustness of the results to different choices of bandwidth. Accordingly, we analyze the data with 0.5-mile, 0.78-mile,1-mile, 1.25-mile and 1.5-mile bandwidths around the 1905 allotment boundary, using both sharp and fuzzy RD designs, in addition to the optimal bandwidth.

Furthermore, we implement the non-parametric, bias-corrected robust inference procedure proposed by Calonico, Cattaneo, and Titiunik (2014) to select the functional form for the running variable ($f(\cdot)$, $g(\cdot)$, and $h(\cdot)$) and to study the discontinuities at the boundary more closely. This approach can be used in contexts with a large number of observations very 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). To build the nonparametric function of the running variables, we fit the 1st, 2nd, 3rd, 4th order local polynomial regression. It is common in regression discontinuity analysis to control for 3rd, 4^{th,} or higher-degree polynomials of the forcing variable. However, Gelman and Imbens (2017) argue that high-order polynomials are ill-suited to regression discontinuity analysis because they lead to noisy estimates, sensitivity to the degree of the polynomial, and poor coverage of confidence intervals. Instead, they recommended using estimators based on local linear or quadratic polynomials. We present results using 2nd order polynomial and include the 1st, 3rd, and 4th order polynomial results in the Appendix as robustness checks.

5. Results

5.1 Sharp RD Regression Results

We begin by testing the 1905 allotment boundary impact on agriculture and crop choice variables using the sharp-RD design on the lands where ownership do not change. This is similar to an intent-to-treat specification. Figure 4 plots soil quality and agricultural activities by distance to boundary by land ownership changes. Land moving from tribal to private ownership has higher irrigation rates, sprinkler-irrigation rates and high-value crop rates. This implies that better land was transferred from tribal to private ownership between 1905 and 2017.

Table 5 shows the empirical result of the sharp RD design using different bandwidth and a second-order polynomial of the running variable. First, we estimate the effect on soil productivity, using the soil productivity index as the dependent variable. Column 1 of Table 4 limits the sample to parcels within 1.5 miles of the 1905 allotment boundary, and columns 2 – 5 restrict it to fall within 1.25, 1, 0.75, and 0.5 miles, respectively. Column 6 reports the allotment effect with the optimal bandwidth obtained from nonparametric specification and column 7 indicates the optimal bandwidth. Rows 2-7 present the results for agricultural rate, irrigation rate, sprinkler-irrigation rate, and high-value crops rate as the dependent variable. Controlling for township, soil productivity index and elevation ensures that we are comparing parcels in close geographic proximity with similar soil quality and elevation. Appendix Table A2-1 to Table A2-7 examine robustness of the main specification to multiple control variables of 1st, 3rd, 4th order polynomials.

The results for soil productivity indicate that the treatment coefficients are positive but not statistically significant at the 10% level. While there are no apparent differences in rates of agriculture and irrigation on allotted lands, allotted lands see around a 12-percentage point lower rate of sprinkler irrigation (-0.146 to -0.102). These negative effects decrease as the bandwidth is reduced, but remain statistically significant at the 1% level. 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 economically similar across the four specifications of the RD polynomial,[10] and we are unable to reject that they are statistically identical (shown in Appendix Table A2-5). The coefficients for high-value crops also show a decrease across the 1905 allotment boundary using both the CDL and WRL data. The negative allotment coefficients range from -0.046 to -0.037 in CDL dataset and -0.014 to -0.009 in WRL

[10] Table A2-5 shows the sharp RD results of sprinkler irrigation rate using 1st, 2nd, 3rd, 4th order polynomial. The negative allotment effect (ranging from -0.146 to -0.093) is statistically significant at the 1% level.

dataset.[11] This implies that even excluding a large portion of land with high-value crops that has been transferred out of tribal control, tribal lands have lower levels of high-value crops.[12]

5.2 Fuzzy RD Regression Results

Table 6 reports the estimates of average treatment effect from the two-stage, fuzzy RD approach under different bandwidth choices. In all but the last set, we consider a fixed bandwidth from the 2017 tribal boundary to each parcel boundary, while the last set evaluates the average treatment effects with the optimal bandwidth choice. Each cell in this table reports an estimate of the average treatment effect for different bandwidths for a second-order polynomial of the running variable. Appendix Table A3-1 to Table A3-7 examine the robustness of the main specification, which demonstrate that the 2017 tribal boundary effects on each dependent variable are generally similar across different polynomial orders. As the bandwidth is increased, there is a modest decrease in the size of the treatment effect for 2nd, 3rd and 4th polynomial order.

Table 6 provides a rigorous analysis of average treatment effect by considering the effect of key covariates that might affect irrigation rate inside and outside the tribal land boundary. While soil productivity is consistently higher inside the boundary, the rate of irrigation, sprinkler irrigation, and high-value crops are lower. The tribal boundary effect lowers the irrigation rate by around eighteen percentage points (-0.195 to -0.177) within the reservation. The treatment coefficients are economically similar when we apply multiple controls, and we are unable to reject that they are statistically identical. The treatment effects remain similar as the bandwidth decreases and polynomial order increases (Appendix Table A3-4). Similarly, tribal land sees an

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[11] This negative effect still exists when we choose the different order polynomials, see Table A2-6 and Table A2-7.

[12] The sharp RD results are illustrated in Fig A1-1 to A1-5. Each subfigure shows one choice of polynomial order plot. Based on the inspection of these plots, it is evident that the 2nd order polynomial regression models fit the data better than 1st, 3rd and 4th order polynomial models. Higher order polynomial regression models are more easily affected by outliers but generally provide a better fit for the data. The subfigures uniformly confirm the presence of a significant discontinuity at 1905 allotment boundary, thus corroborating the main findings from Table 5.

approximately 31 percentage point lower (-0.323 to -0.305) sprinkler-irrigated rate compared to non-tribal land. After controlling for covariates, the treatment effect coefficients are still statistically significant at the 1% level. The average treatment estimates are consistent across different bandwidth choices and multiple covariates.

In row 1 of Table 6, we describe estimates of treatment effect, using soil productivity index as the dependent variable. The tribal boundary effect increases the soil productivity index by one full rank in subjected parcels (1.011 to 1.143). After controlling for township and elevation, the treatment effect coefficients are still statistically significant at the 1% level. This indicates that land quality is statistically higher on tribal land. This result moves in the opposite direction of the selection effect we might suspect, where better land outside the reservation has more investment and higher-value crops. Instead, we see more irrigation and high-value crops on the (relatively) poorer land outside the reservation. Rows 6 and 7 report the high-value crop difference across the tribal boundary today. Each cell reports the coefficient on $\widehat{Uintah2}017$ for different bandwidth choices. As an example, the average tribal boundary effect of high-value crop rate is 14.7 percentage points lower on tribal land than on private land in the CDL data set, and 4.3 percentage points lower on tribal land in the WRL data set.[13]

6. Conclusion

This paper explores the effect of tribal land ownership on agricultural development caused, at least in part, by insecure property rights on American Indian Reservations. Our economic framework suggests fee-simple landowners with secure property rights are more likely to obtain access to commercial credit and borrow money to invest capital intensive

[13] The negative effect ranges from -0.153 to -0.143 in CDL dataset and -0.045 to -0.042 in WRL dataset. The non-parametric fuzzy RD results are illustrated in Figures A2-1 to A2-5. Each subfigure shows one choice of polynomial order plot. Based on the inspection of these plots, it is evident that the 2nd order polynomial regression models fit the data better than 1st, 3rd and 4th order polynomial models.

improvements. The effect is that Uintah reservation lands see less intensive cultivation and lower value crops. Our findings illustrate that when controlling for land quality and geographic location, fee-simple land has an irrigation rate approximately 18 percentage points higher than tribal land. Conditional on being irrigated, tribal land is 31 percentage points less likely to be sprinkler-irrigated today. Moreover, fee-simple farms have higher amounts of high-value crops within 1.5 miles of the boundary with reservation land.

Evaluating allotment effects in 1905 and tribal boundary effects together, we conclude that agricultural irrigation 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 insecure property rights on tribal trust land. However, there are several alternative explanations for the observed results, including issues with BIA irrigation projects, a lack of access to USDA loan programs, and other government support and subsidies to which fee-simple farmers may receive preferential access. The results do suggest that trust ownership creates significant barriers to the acquisition of capital for agricultural investment. While access to investment capital 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.

FIGURES

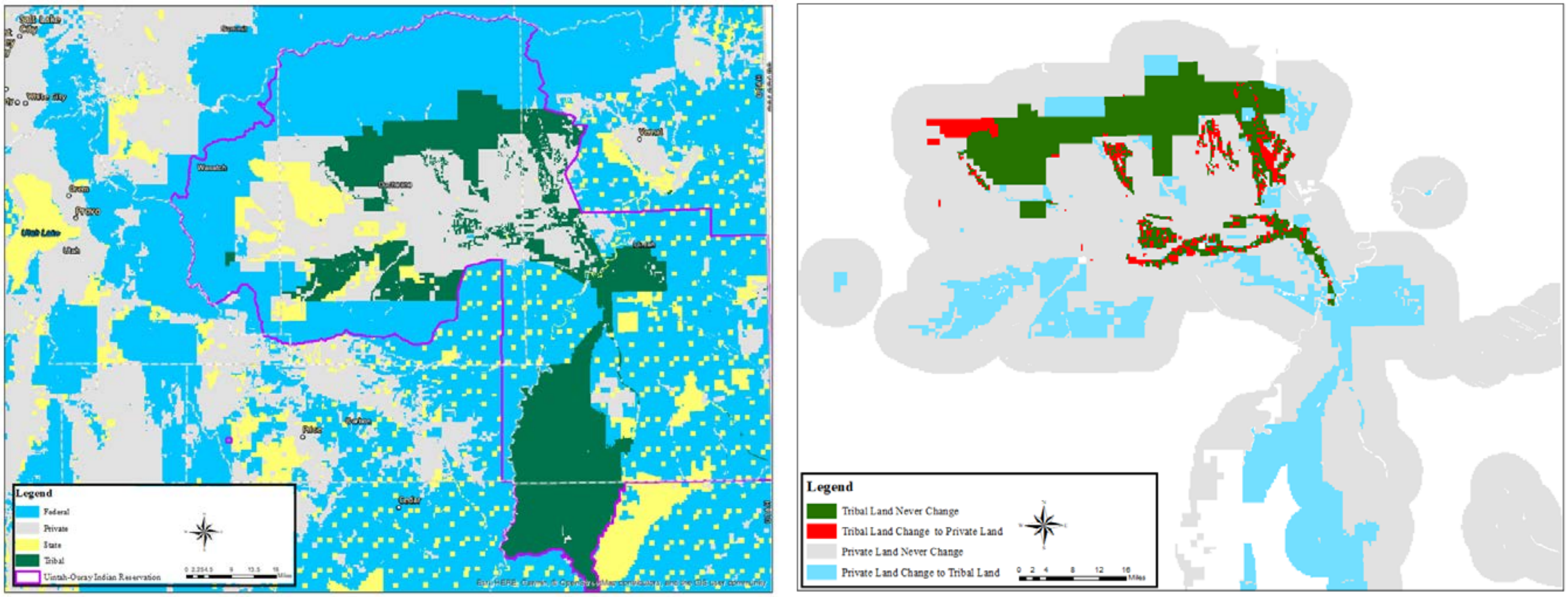

Figure 1. – Left: Land ownership map of Uintah and Ouray Indian Reservation in 2017. Federal (Blue) represents land owned by federal government, private (Grey) represents privately owned land (the owner can be tribal member or non-tribal member), tribe (Green) represents tribal land, and state (Yellow) represents state owned land. Right: Land ownership changes map of Uintah and Ouray Indian Reservation in 2017. Green represents tribe owned land in both 1905 and 2017, red represents the land changes from tribe to private owner, grey represents private owned land in both 1905 and 2017, and blue is the land changes from private owner to tribe.

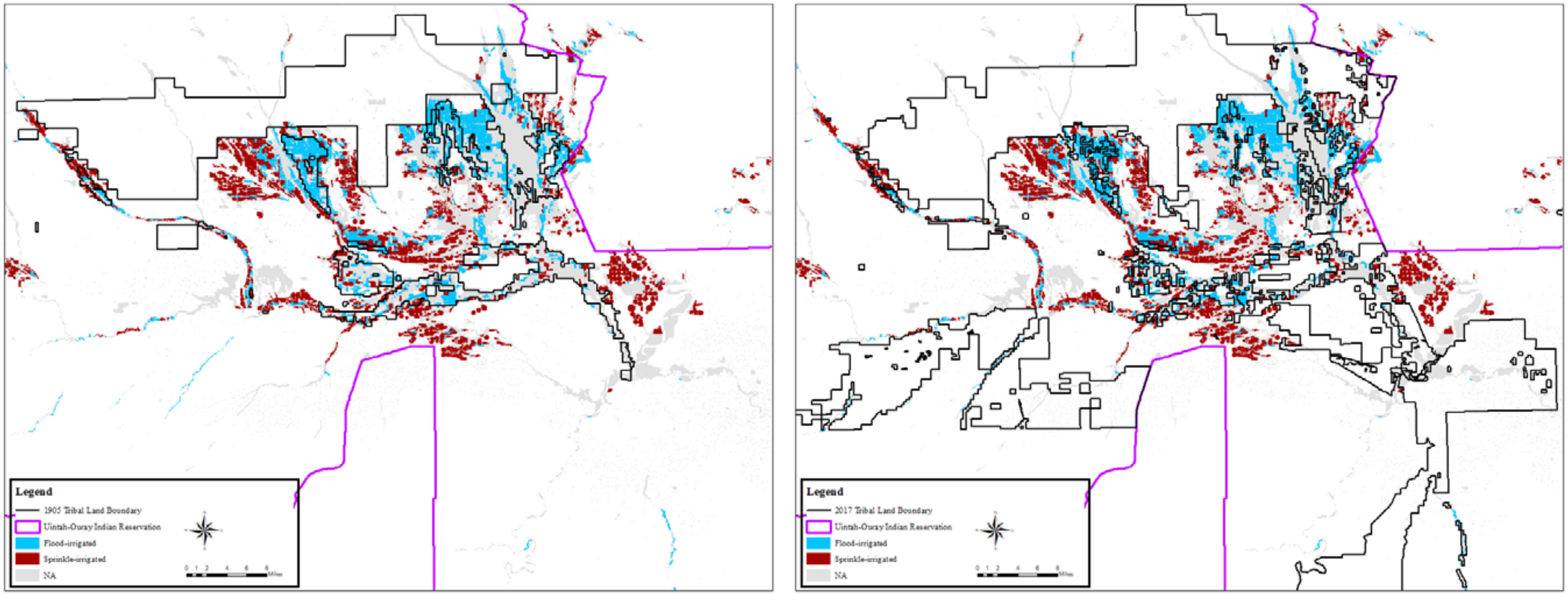

Figure 2. – Left: Water-related-land-use parcels in Uintah and Ouray Indian Reservation in 1905. Right: Water-related-land-use parcels in Uintah and Ouray Indian Reservation in 2017. Blue represents flood-irrigated land, brown represents sprinkler-irrigated land, light grey represents non-irrigated land.

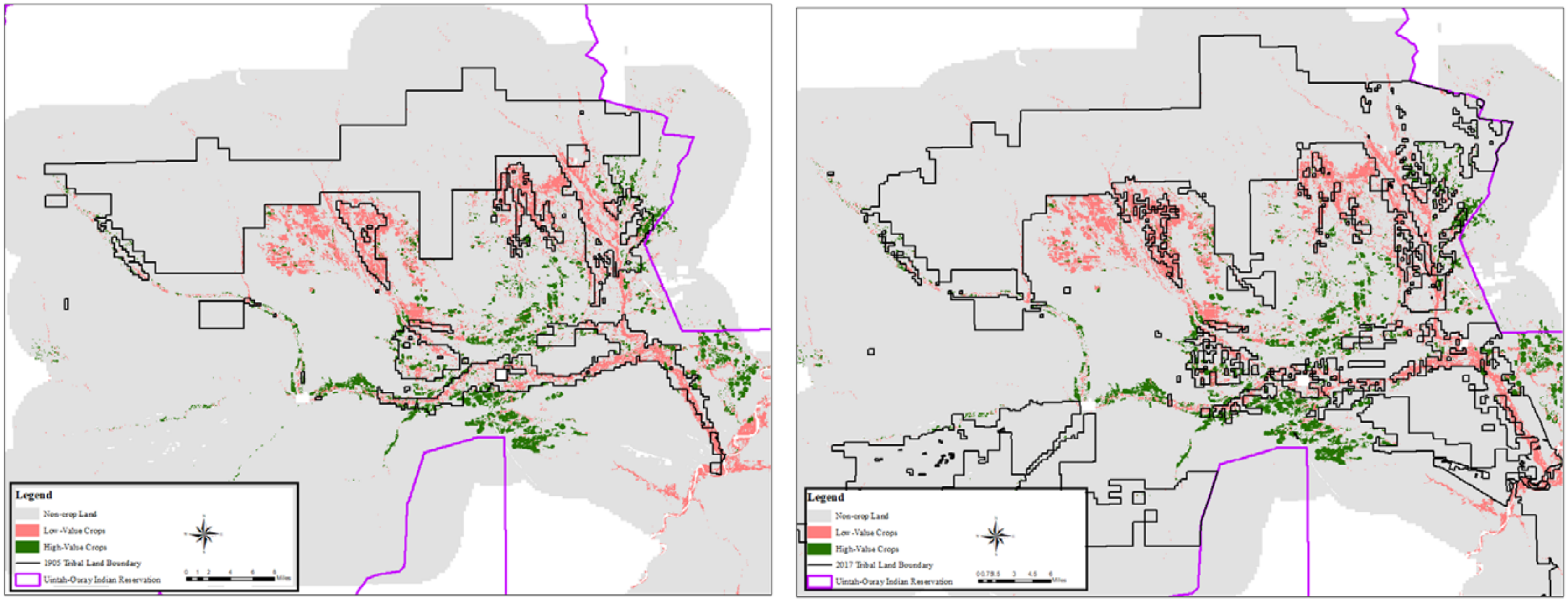

Figure 3. – Left: Crop value distribution map for 1905 allotment boundary. Right: Crops value distribution map for 2017 tribal boundary. Pink represents low value crops, green represents high value crops, and light grey represents non-crop land.

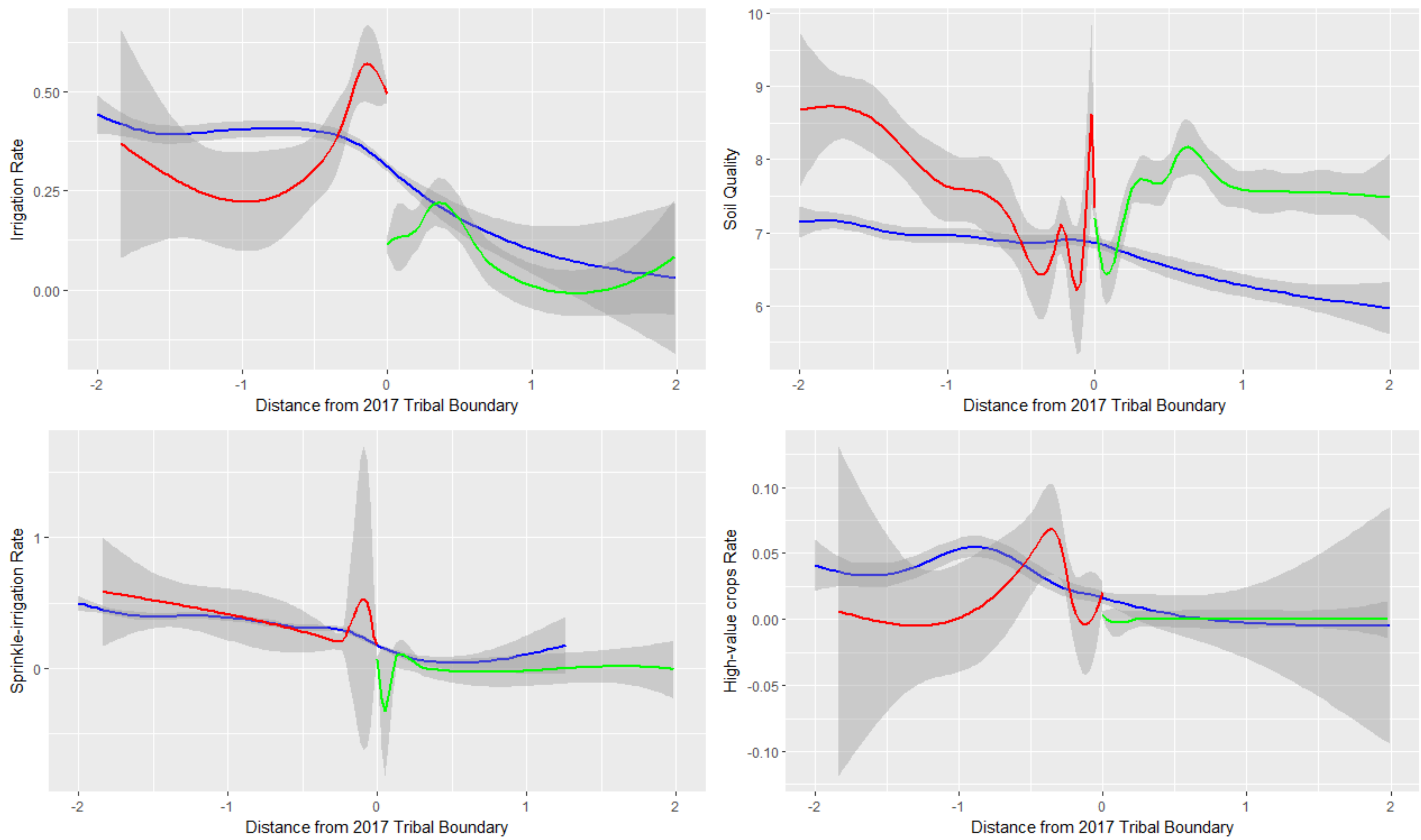

Figure 4. – Top left: Irrigation rate difference due to land ownership changes. Top right: Soil quality difference due to land ownership changes. Bottom left: Sprinkler-irrigation rate difference due to land ownership changes. Bottom right: High-value crops rate difference due to land ownership changes. Positive range of x-axis represents tribal land in 2017, and negative range of x-axis represents private land in 2017. Red line represents the trend of lands changing land ownership from tribal to private between 1905 and 2017. Green line represents the trend of lands changing landownership from private to tribal between 1905 and 2017. Blue line represents the trend of lands with no change in land ownership.

TABLES

Table 1 Summary Statistics

	Formula	< 2 Miles 1905 Allotment Boundary				< 2 Miles 2017Tribal Boundary			
		Observation		Mean		Observation		Mean	
		Tribal	Private	Tribal	Private	Tribal	Private	Tribal	Private
Agricultural Rate (CDL)	$AgRate = \frac{Agricultural\ Land}{Total\ Land}$	3,343	5,961	0.342	0.300	3,411	8,560	0.301	0.301
				(0.305)	(0.303)			(0.309)	(0.305)
Agricultural Rate (WRL)		2,753	5,425	0.659	0.588	2,190	7,202	0.574	0.590
				(0.361)	(0.352)			(0.397)	(0.351)
Irrigation Rate	$IrrRate = \frac{Irrigated\ Land}{Total\ Land}$	3,168	6,101	0.347	0.384	2,659	8,032	0.228	0.397
				(0.402)	(0.380)			(0.357)	(0.381)
Sprinkle-irrigated Rate	$SprkRate = \frac{Sprinkle\ Land}{Irrigated\ Land}$	2,060	4,498	0.129	0.326	1,431	6,065	0.073	0.312
				(0.286)	(0.361)			(0.219)	(0.361)
High Value Crops Rate (CDL)	$HcropRate = \frac{Hcrop\ Land}{Total\ Land}$	3,343	5,961	0.060	0.116	3,411	8,560	0.024	0.119
				(0.177)	(0.233)			(0.109)	(0.237)
High Value Crops Rate (WRL)		2,753	5,425	0.015	0.027	2,190	7,202	0.008	0.032
				(0.099)	(0.130)			(0.071)	(0.144)

Notes: The sample contains 54,377 observations located less than 2 miles from either 1905 Allotment Boundary or 2017 Tribal Boundary. In Column 3 to 6, the sample includes only observations located less than 2 miles from the 1905 Allotment Boundary. Column 7 to 10 represent the sample located less than 2 miles from the 2017 Tribal Boundary. In the Uintah and Ouray Indian Reservation, only two types of irrigation system are used: flood irrigation system and sprinkler irrigation ($Irrigated\ land = Flood\ Land + Sprinkle\ Land$). Standard errors are provided in the parenthesis.

Table 2 1905 Allotment Boundary Balance Test

	< 0.5 Miles			*< 0.75 Miles*			*< 1 Miles*			*< 1.25 Miles*			*< 1.5 Miles*		
	inside	outside	statistics	inside	outside	statistics	inside	outside	statistics	inside	outside	statistics	inside	outside	statistics
Climate Statistics															
Observations	1,001	1,229		1,199	1,602		1,368	1,954		1,503	2,290		1,624	2,578	
Annual Mean	43.8	43.7	(1.26)	43.6	43.7	(-0.544)	43.4	43.6	(-1.3)	43.2	43.5	(-3.11)***	43.1	43.5	(-4.17)***
Temperature (°F)			*[6.2E+5]*			*[9.2E+5]**			*[1.2E+6]****			*[1.5E+6]****			*[1.8E+6]****
Max Temperature of	85.4	85.3	(0.74)	85.0	85.2	(-1.23)	84.6	85.0	(-2.41)**	84.2	85.0	(-4.33)***	83.9	84.9	(-5.66)***
Warmest Month(°F)			*[6.2E+5]*			*[9.2E+5]***			*[1.2E+6]****			*[1.5E+6]****			*[1.8E+6]****
Min Temperature of	5.5	5.4	(0.90)	5.6	5.4	(2.89)***	5.8	5.4	(5.50)***	5.8	5.4	(7.61)***	5.9	5.4	(9.78)***
Coldest Month(°F)			*[6.4E+5]**			*[1.1E+6]****			*[1.5E+6]****			*[2.1E+6]****			*[2.6E+6]****
Annual Precipitation(mm)	249	257	(-1.89)*	256	258	(-0.29)	261	262	(0.58)	266	263	(2.33)**	269	265	(3.41)***
			[5.9E+5]			*[9.6E+5]*			*[1.4E+6]**			*[1.8E+6]****			*[2.3E+6]****
Precipitation of Driest	15.0	15.7	(-1.94)*	15.5	15.8	(-0.59)	16.0	16.1	(0.53)	16.4	16.2	(2.10)**	16.8	16.3	(3.30)***
Month(mm)			*[5.9E+5]***			*[9.4E+5]*			*[1.4E+6]*			*[1.8E+6]***			*[2.2E+6]****
Land Statistics															
Observations	4,476	5,511		5,330	7,290		5,992	8,833		6,596	10,369		7,088	11,810	
Elevation(m)	1,872	1,855	(2.51)**	1,901	1,865	(5.89)***	1,927	1,876	(8.75)***	1,949	1,886	(11.50)***	1,966	1,894	(13.80)***
			*[1.3E+7]***			*[2.1E+7]****			*[2.9E+7]****			*[3.9E+7]****			*[4.8E+7]****
Soil Productivity	7.1	7.1	(1.65)*	7.0	7.0	(1.01)	7.0	7.0	(-0.352)	6.9	6.9	(-1.53)	6.8	6.9	(-2.61)***
			*[1.3E+7]***			*[2.0E+7]**			*[2.7E+7]*			*[3.4E+7]*			*[4.2E+7]*

Notes: The unit of observation is PLSS QuarterQuarter Section. Summary statistics table show two datasets: climate statistics and land statistics dataset. The land statistics dataset contains all the private and tribal parcels in the Uintah and Ouray Indian reservation, while the climate statistics dataset contains only most representative PLSS parcels. Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%.

Table 3 1905 Allotment Border Balance Test (Never switched land)

	< 0.5 Miles			*< 0.75 Miles*			*< 1 Miles*			*< 1.25 Miles*			*< 1.5 Miles*		
	inside	outside	statistics	inside	outside	statistics	inside	outside	statistics	inside	outside	statistics	inside	outside	statistics
							Climate Statistics								
Observations	748	1,030		892	1,345		1,053	1,637		1,164	1,939		1,282	2,195	
Annual Mean Temperature	43.6	43.7	(-0.715)	43.4	43.7	(-1.99)*	43.2	43.5	(-3.19)***	43.1	43.5	(-4.05)***	42.9	43.4	(-5.2)***
(°F)			*[3.6E+5]**			*[5.5E+5]****			*[7.5E+5]****			*[9.5E+5]****			*[1.2E+6]****
Max Temperature of	84.9	85.2	(-1.16)	84.5	85.1	(-2.71)***	84.1	84.9	(-4.31)***	83.8	84.9	(-5.4)***	83.6	84.8	(-6.83)***
Warmest Month(°F)			*[3.6E+5]***			*[5.4E+5]***			*[7.4E+5]****			*[9.4E+5]****			*[1.1E+6]****
Min Temperature of	5.68	5.41	(2.27)**	5.81	5.41	(4.32)***	5.97	5.43	(7.16)***	6.06	5.44	(9.04)***	6.15	5.45	(11.40)***
Coldest Month(°F)			*[4.4E+5]****			*[7.1E+5]****			*[1.1E+6]****			*[1.5E+6]****			*[1.9E+6]****
Annual Precipitation(mm)	254	258	(-0.0469)	259	260	(0.97)	265	263	(2.21)**	268	265	(2.97)***	271	266	(4.16)***
			[3.9E+5]			*[6.3E+5]**			*[9.4E+5]**			*[1.2E+6]****			*[1.6E+6]****
Precipitation of Driest	15.6	15.8	(0.12)	16	15.9	(1.01)	16.5	16.2	(2.49)**	16.7	16.3	(3.18)***	17.1	16.4	(4.45)***
Month(mm)			*[3.8E+5]*			*[6.1E+5]*			*[9.1E+5]***			*[1.2E+6]****			*[1.5E+6]****
							Land Statistics								
Observations	3,202	4,574		3,904	6,067		4,487	7,382		5,030	8,697		5,479	9,936	
Elevation(m)	1,898	1,853	(5.96)***	1,928	1,867	(9.07)***	1,953	1,880	(11.50)***	1,973	1,892	(13.90)***	1,990	1,900	(16.10)***
			*[7.9E+6]****			*[1.3E+7]****			*[1.9E+7]****			*[2.6E+7]****			*[3.3E+7]****
Soil Productivity	7.0	7.2	(-3.81)***	6.9	7.1	(-5.2)***	6.8	7.1	(-6.93)***	6.7	7.1	(-8.53)***	6.7	7.1	(-10)***
			*[7.0E+6]****			*[1.1E+7]****			*[1.6E+7]****			*[2.1E+7]****			*[2.6E+7]****

Notes: The unit of observation is PLSS QuarterQuarter Section. Summary statistics table show two datasets: climate statistics and land statistics dataset. The land statistics dataset contains all the private and tribal parcels in the Uintah and Ouray Indian reservation, while the climate statistics dataset contains only most representative PLSS parcels. Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%.

Table 4 2017 Tribal Boundary Balance Test

	< 0.5 Miles			< 0.75 Miles			< 1 Miles			< 1.25 Miles			< 1.5 Miles		
	inside	outside	statistics	inside	outside	statistics	inside	outside	statistics	inside	outside	statistics	inside	outside	statistics
							Climate Statistics								
Observations	2,332	2,830		2,824	3,653		3,215	4,395		3,536	5,232		3,810	5,919	
Annual Mean	44.0	44.4	(-4.73)***	43.9	44.3	(-5.82)***	43.8	44.3	(-6.93)***	43.7	44.2	(-6.27)***	43.6	44.1	(-6.95)***
Temperature (°F)			*[3.0E+6]****			*[4.7E+6]****			*[6.4E+6]****			*[8.4E+6]****			*[1.0E+7]****
Max Temperature of	85.5	86.1	(-4.61)***	85.3	86.1	(-5.73)***	85.0	85.9	(-7.27)***	84.9	85.8	(-6.91)***	84.7	85.6	(-7.91)***
Warmest Month(°F)			*[3.1E+6]****			*[4.7E+6]****			*[6.3E+6]****			*[8.4E+6]****			*[1.0E+7]****
Min Temperature of	5.9	5.8	(0.73)	6.0	5.9	(1.18)	6.1	5.9	(2.93)***	6.2	5.9	(3.66)***	6.3	6.0	(4.88)***
Coldest Month(°F)			*[3.4E+6]****			*[5.4E+6]****			*[7.6E+6]****			*[1.0E+7]****			*[1.2E+7]****
Annual	270	263	(3.30)***	274	265	(4.13)***	278	268	(5.15)***	280	272	(4.52)***	283	275	(5.02)***
Precipitation(mm)			*[3.5E+6]****			*[5.4E+6]****			*[7.5E+6]****			*[9.8E+6]****			*[1.2E+7]****
Precipitation of	16.3	15.7	(3.42)***	16.6	15.9	(4.28)***	17.0	16.1	(5.37)***	17.1	16.4	(4.98)***	17.3	16.6	(5.52)***
Driest Month(mm)			*[3.5E+6]****			*[5.4E+6]****			*[7.5E+6]****			*[9.8E+6]****			*[1.2E+7]****
							Land Statistics								
Observations	10,480	12,750		12,627	16,421		14,233	19,811		15,630	23,232		16,804	26,516	
Elevation(m)	1,887	1,852	(7.39)***	1,910	1,864	(10.60)***	1,927	1,876	(12.50)***	1,940	1,887	(13.90)***	1,951	1,896	(15.00)***
			*[6.9E+7]****			*[1.1E+8]****			*[1.5E+8]****			*[2.0E+8]****			*[2.4E+8]****
Soil Productivity	7.3	6.9	(7.35)***	7.3	6.9	(8.92)***	7.3	6.9	(9.03)***	7.3	6.9	(8.60)***	7.3	6.9	(8.09)***
			*[7.3E+7]****			*[1.1E+8]****			*[1.5E+8]****			*[2.0E+8]****			*[2.4E+8]****

Notes: The unit of observation is PLSS QuarterQuarter Section. Summary statistics table show two datasets: climate statistics and land statistics dataset. The land statistics dataset contains all the private and tribal parcels in the Uintah and Ouray Indian reservation, while the climate statistics dataset contains only most representative PLSS parcels. Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%.

Table 5 Sharp RD Results (Second order polynomial)

Sample Within	Estimated Average Treatment Effects							Control Variables		
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	Optimal Miles	Elevation	Townships	Soil Productivity
Soil Productivity Index										
Allotment1905	0.139	0.117	0.103	0.084	0.067	0.139	1.289	√	√	
	(0.115)	(0.118)	(0.120)	(0.122)	(0.127)	(0.115)				
Agricultural Rate (CDL)										
Allotment1905	0.004	0.004	0.007	0.008	0.015	0.003	1.328	√	√	√
	(0.018)	(0.019)	(0.019)	(0.020)	(0.020)	(0.018)				
Agricultural Rate (WRL)										
Allotment1905	0.040	0.044	0.041*	0.040	0.037	0.037	1.699	√	√	√
	(0.024)	(0.025)	(0.026)	(0.026)	(0.027)	(0.023)				
Irrigation Rate										
Allotment1905	0.005	0.015	0.017	0.018	0.016	-0.002	1.595	√	√	√
	(0.024)	(0.025)	(0.025)	(0.026)	(0.027)	(0.023)				
Sprinkle-irrigated Rate										
Allotment1905	-0.146***	-0.133***	-0.124***	-0.119***	-0.102***	-0.120***	0.954	√	√	√
	(0.026)	(0.027)	(0.028)	(0.028)	(0.029)	(0.028)				
High-value Crops Rate (CDL)										
Allotment1905	-0.046***	-0.046***	-0.042***	-0.038***	-0.037**	-0.045***	0.972	√	√	√
	(0.013)	(0.014)	(0.014)	(0.014)	(0.015)	(0.014)				
High-value Crops Rate (WRL)										
Allotment1905	-0.012	-0.013*	-0.014*	-0.014*	-0.013	-0.009	2.162	√	√	√
	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)	(0.006)				

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis. The second order polynomial sharp RD results of five different dependent variables are shown in the table. Row 2 and 3 shows the agricultural rate RD effects of two different dataset, CDL and WRL, while the row 6 and 7 shows the RD results of high-value crop rate in these two datasets. Five different bandwidths choices results are listed in column 1 to 5. Elevation, townships and soil productivity are controlled.

Table 6 Fuzzy RD Results (Second order polynomial)

Sample Within	Estimated Average Treatment Effects							Control Variables		
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	Optimal Miles	Elevation	Townships	Soil Productivity
Soil Productivity Index										
Tribal2017	1.011***	1.060***	1.111***	1.123***	1.143***	1.025***	1.521	√	√	
	(0.385)	(0.400)	(0.414)	(0.422)	(0.435)	(0.359)				
Agricultural Rate (CDL)										
Tribal2017	-0.048	-0.043	-0.030	-0.019	-0.003	-0.048	1.323	√	√	√
	(0.033)	(0.034)	(0.036)	(0.036)	(0.037)	(0.034)				
Agricultural Rate (WRL)										
Tribal2017	-0.020	-0.026	-0.027	-0.025	-0.024	-0.024	1.355	√	√	√
	(0.039)	(0.041)	(0.042)	(0.043)	(0.044)	(0.040)				
Irrigation Rate										
Tribal2017	-0.195***	-0.193***	-0.187***	-0.182***	-0.177***	-0.192***	1.396	√	√	√
	(0.042)	(0.043)	(0.044)	(0.045)	(0.046)	(0.043)				
Sprinkle-irrigated Rate										
Tribal2017	-0.323***	-0.319***	-0.313***	-0.309***	-0.305***	-0.320***	1.319	√	√	√
	(0.044)	(0.046)	(0.047)	(0.047)	(0.048)	(0.045)				
High-value Crops Rate (CDL)										
Tribal2017	-0.147***	-0.147***	-0.147***	-0.143***	-0.144***	-0.153***	1.316	√	√	√
	(0.024)	(0.025)	(0.026)	(0.026)	(0.027)	(0.026)				
High-value Crops Rate (WRL)										
Tribal2017	-0.043***	-0.044***	-0.045***	-0.044***	-0.042***	-0.044***	1.168	√	√	√
	(0.013)	(0.013)	(0.014)	(0.014)	(0.014)	(0.013)				

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis. The second order polynomial fuzzy RD results of five different dependent variables are shown in the table. Row 2 and 3 shows the agricultural rate RD effects of two different dataset, CDL and WRL, while the row 6 and 7 shows the RD results of high-value crop rate in these two datasets. Five different bandwidths choices results are listed in column 1 to 5. Elevation, townships and soil productivity are controlled.

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Appendix

Table A1 Crops Value Classification

Crops	Crop Value	Crop Value Indicator
Alfalfa	Low	0
Beans	High	1
Berries	High	1
Corn	High	1
Dry Alfalfa	Low	0
Dry Beans	High	1
Dry Grain	High	1
Dry Grain/Seeds	High	1
Dry Oats	High	1
Dry Safflower	High	1
Fallow-Irrigated Ag	Low	0
Fallow-Irrigated Land	Low	0
Grain	High	1
Grass Hay	Low	0
Grass Hay-sub-irrigated	Low	0
Idle-Irrigated Ag	Low	0
Idle-Irrigated Land	Low	0
Idle-Irrigated Pasture	Low	0
Melon/Pumpkin/Squash	High	1
Oats	High	1
Onions	High	1
Orchard	High	1
Other Horticulture	High	1
Other Vegetables	High	1
Pasture	Low	0
Pasture-sub-irrigated	Low	0
Potatoes	High	1
Safflower	High	1
Sorghum	High	1
Tomatoes	High	1
Turf Farms	High	1
Vineyard	High	1

Table A2-1 Sharp RD Results of Soil Productivity Index

Sample Within	Soil Productivity index						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Allotment1905	0.063	0.083	0.056	0.051	0.026	0.063	1.281
	(0.098)	(0.104)	(0.111)	(0.117)	(0.120)	(0.098)	
Second order polynomial							
Allotment1905	0.139	0.117	0.103	0.084	0.067	0.139	1.289
	(0.115)	(0.118)	(0.120)	(0.122)	(0.127)	(0.115)	
Third order polynomial							
Allotment1905	0.137	0.107	0.090	0.036	-0.010	0.137	1.732
	(0.122)	(0.123)	(0.124)	(0.129)	(0.138)	(0.122)	
Fourth order polynomial							
Allotment1905	0.143	0.134	0.068	0.005	-0.318**	0.143	2.168
	(0.125)	(0.126)	(0.132)	(0.138)	(0.147)	(0.125)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Observations (out/in)	(8424/6991)	(7185/6542)	(5870/5999)	(4555/5416)	(3062/4714)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A2-2 Sharp RD Results of Agricultural Rate (CDL dataset)

Sample Within	Agricultural Rate						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Allotment1905	0.010	0.006	0.003	0.008	0.009	0.004	0.611
	(0.015)	(0.016)	(0.018)	(0.019)	(0.019)	(0.018)	
Second order polynomial							
Allotment1905	0.004	0.004	0.007	0.008	0.015	0.003	1.328
	(0.018)	(0.019)	(0.019)	(0.020)	(0.020)	(0.018)	
Third order polynomial							
Allotment1905	0.005	0.008	0.011	0.015	0.020	0.003	2.222
	(0.019)	(0.020)	(0.020)	(0.020)	(0.021)	(0.018)	
Fourth order polynomial							
Allotment1905	0.009	0.012	0.014	0.020	0.022	0.004	2.070
	(0.020)	(0.020)	(0.020)	(0.021)	(0.022)	(0.019)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(3398/3133)	(2970/3087)	(2521/2998)	(2077/2893)	(1486/2714)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A2-3 Sharp RD Results of Agricultural Rate (WRL dataset)

Sample Within	Agricultural Rate						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Allotment1905	0.026*	0.033	0.042	0.045	0.046*	0.040	0.731
	(0.020)	(0.021)	(0.023)	(0.025)	(0.026)	(0.022)	
Second order polynomial							
Allotment1905	0.040	0.044	0.041*	0.040	0.037	0.037	1.699
	(0.024)	(0.025)	(0.026)	(0.026)	(0.027)	(0.023)	
Third order polynomial							
Allotment1905	0.043	0.039	0.039	0.036*	0.031	0.038*	1.140
	(0.026)	(0.026)	(0.026)	(0.027)	(0.028)	(0.026)	
Fourth order polynomial							
Allotment1905	0.037	0.036	0.033*	0.034	0.030*	0.039	1.603
	(0.026)	(0.027)	(0.027)	(0.028)	(0.030)	(0.026)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(3337/2623)	(2922/2596)	(2475/2545)	(2008/2479)	(1415/2347)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A2-4 Sharp RD Results of Irrigation Rate

Sample Within	Irrigation Rate						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Allotment1905	-0.020	-0.009	0.007	0.019	0.026	0.019	0.483
	(0.020)	(0.021)	(0.023)	(0.025)	(0.026)	(0.025)	
Second order polynomial							
Allotment1905	0.005	0.015	0.017	0.018	0.016	-0.002	1.595
	(0.024)	(0.025)	(0.025)	(0.026)	(0.027)	(0.023)	
Third order polynomial							
Allotment1905	0.017	0.015	0.016	0.014	-0.001	0.012	1.375
	(0.026)	(0.026)	(0.026)	(0.027)	(0.028)	(0.026)	
Fourth order polynomial							
Allotment1905	0.012	0.012	0.008	0.002	-0.020	0.012	1.567
	(0.026)	(0.027)	(0.027)	(0.028)	(0.030)	(0.026)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(3692/3000)	(3230/2963)	(2738/2906)	(2218/2906)	(1567/2661)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A2-5 Sharp RD Results Sprinkle-irrigated Rate

Sample Within	Sprinkle-irrigated Rate						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Allotment1905	-0.129***	-0.140***	-0.136***	-0.123***	-0.115***	-0.125***	0.475
	(0.021)	(0.023)	(0.025)	(0.027)	(0.028)	(0.027)	
Second order polynomial							
Allotment1905	-0.146***	-0.133***	-0.124***	-0.119***	-0.102***	-0.120***	0.954
	(0.026)	(0.027)	(0.028)	(0.028)	(0.029)	(0.028)	
Third order polynomial							
Allotment1905	-0.131***	-0.124***	-0.118***	-0.104***	-0.093***	-0.117***	0.968
	(0.028)	(0.028)	(0.028)	(0.029)	(0.030)	(0.028)	
Fourth order polynomial							
Allotment1905	-0.123***	-0.118***	-0.108***	-0.096***	-0.100***	-0.099***	0.794
	(0.028)	(0.029)	(0.029)	(0.030)	(0.031)	(0.029)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(2819/1871)	(2467/1956)	(2083/1926)	(1698/1881)	(1203/1797)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A2-6 Sharp RD Results of High-value Crops Rate (CDL dataset)

Sample Within	High-value Crops Rate (2012)						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Allotment1905	-0.046***	-0.045***	-0.045***	-0.041***	-0.037***	-0.041***	0.498
	(0.011)	(0.012)	(0.013)	(0.014)	(0.014)	(0.014)	
Second order polynomial							
Allotment1905	-0.046***	-0.046***	-0.042***	-0.038***	-0.037**	-0.045***	0.972
	(0.013)	(0.014)	(0.014)	(0.014)	(0.015)	(0.014)	
Third order polynomial							
Allotment1905	-0.045***	-0.042***	-0.038***	-0.035**	-0.038**	-0.046***	1.814
	(0.014)	(0.014)	(0.014)	(0.015)	(0.016)	(0.014)	
Fourth order polynomial							
Allotment1905	-0.042***	-0.039***	-0.038**	-0.040***	-0.044***	-0.052***	2.171
	(0.014)	(0.015)	(0.015)	(0.016)	(0.016)	(0.014)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(3398/3133)	(2970/3087)	(2521/2998)	(2077/2893)	(1486/2714)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A2-7 Sharp RD Results of High-value Crops Rate (WRL dataset)

Sample Within	High-value Crops Rate (2012)						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Allotment1905	-0.008	-0.008	-0.010	-0.012	-0.012	-0.005	0.919
	(0.006)	(0.006)	(0.007)	(0.007)	(0.008)	(0.006)	
Second order polynomial							
Allotment1905	-0.012	-0.013*	-0.014*	-0.014*	-0.013	-0.009	2.162
	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)	(0.006)	
Third order polynomial							
Allotment1905	-0.015***	-0.015*	-0.014*	-0.013	-0.015*	-0.011	2.262
	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)	(0.007)	
Fourth order polynomial							
Allotment1905	-0.016**	-0.016*	-0.015*	-0.015	-0.015	-0.016**	1.643
	(0.008)	(0.008)	(0.009)	(0.009)	(0.010)	(0.008)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(3337/2623)	(2922/2596)	(2475/2545)	(2008/2479)	(1415/2347)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A3-1 Fuzzy RD Results of Soil Productivity Index

Sample Within	Soil Productivity index						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Tribal2017	1.015***	0.967***	0.956***	1.014***	1.057***	0.939***	0.681
	(0.314)	(0.334)	(0.358)	(0.385)	(0.408)	(0.364)	
Second order polynomial							
Tribal2017	1.011***	1.060***	1.111***	1.123***	1.143***	1.025***	1.521
	(0.385)	(0.400)	(0.414)	(0.422)	(0.435)	(0.359)	
Third order polynomial							
Tribal2017	1.071**	1.079**	1.083**	1.096**	1.208***	1.001**	1.730
	(0.419)	(0.424)	(0.427)	(0.437)	(0.451)	(0.406)	
Fourth order polynomial							
Tribal2017	1.108**	1.110**	1.043**	1.033**	0.764	1.044**	2.505
	(0.432)	(0.434)	(0.444)	(0.455)	(0.478)	(0.415)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Observations (out/in)	(22882/20438)	(19598/19264)	(16177/17867)	(12787/16261)	(9116/14114)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A3-2 Fuzzy RD Results of Agricultural Rate (CDL dataset)

Sample Within	Agricultural Rate						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Tribal2017	-0.010	-0.029	-0.041	-0.035	-0.021	-0.043	0.796
	(0.025)	(0.027)	(0.030)	(0.033)	(0.036)	(0.032)	
Second order polynomial							
Tribal2017	-0.048	-0.043	-0.030	-0.019	-0.003	-0.048	1.323
	(0.033)	(0.034)	(0.036)	(0.036)	(0.037)	(0.034)	
Third order polynomial							
Tribal2017	-0.032	-0.022	-0.015	0.000	0.011	-0.048	1.963
	(0.036)	(0.036)	(0.036)	(0.037)	(0.038)	(0.034)	
Fourth order polynomial							
Tribal2017	-0.025	-0.015	-0.009	0.002	0.006	0.022	1.674
	(0.036)	(0.036)	(0.037)	(0.037)	(0.038)	(0.040)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(5905/4879)	(5318/4826)	(4649/4744)	(3921/4646)	(3063/4467)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A3-3 Fuzzy RD Results of Agricultural Rate (WRL dataset)

Sample Within	Agricultural Rate						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Tribal2017	-0.010	-0.011	-0.018	-0.024	-0.023	-0.033	0.879
	(0.031)	(0.033)	(0.036)	(0.040)	(0.042)	(0.042)	
Second order polynomial							
Tribal2017	-0.020	-0.026	-0.027	-0.025	-0.024	-0.024	1.355
	(0.039)	(0.041)	(0.042)	(0.043)	(0.044)	(0.040)	
Third order polynomial							
Tribal2017	-0.028	-0.028	-0.025	-0.021	-0.027	-0.026	1.704
	(0.043)	(0.043)	(0.043)	(0.044)	(0.045)	(0.042)	
Fourth order polynomial							
Tribal2017	-0.029	-0.024	-0.022	-0.027	-0.031	-0.027	1.603
	(0.043)	(0.043)	(0.044)	(0.045)	(0.050)	(0.043)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(4954/3540)	(4462/3531)	(3922/3505)	(3345/3470)	(2603/3399)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A3-4 Fuzzy RD Results of Irrigation Rate

Sample Within	Irrigation Rate						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Tribal2017	-0.191***	-0.192***	-0.195***	-0.192***	-0.182***	-0.188***	1.186
	(0.033)	(0.035)	(0.038)	(0.042)	(0.044)	(0.042)	
Second order polynomial							
Tribal2017	-0.195***	-0.193***	-0.187***	-0.182***	-0.177***	-0.192***	1.396
	(0.042)	(0.043)	(0.044)	(0.045)	(0.046)	(0.043)	
Third order polynomial							
Tribal2017	-0.189***	-0.186***	-0.182***	-0.175***	-0.188***	-0.190***	1.179
	(0.045)	(0.045)	(0.045)	(0.046)	(0.048)	(0.045)	
Fourth order polynomial							
Tribal2017	-0.185***	-0.178***	-0.176***	-0.191***	-0.214***	-0.180***	1.142
	(0.045)	(0.045)	(0.046)	(0.047)	(0.052)	(0.045)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(5503/4141)	(4944/4124)	(4344/4090)	(3707/4042)	(2902/3953)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A3-5 Fuzzy RD Results of Sprinkle-irrigation Rate

Sample Within	Sprinkle-irrigated Rate						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Tribal2017	-0.300***	-0.311***	-0.318***	-0.316***	-0.314***	-0.312***	1.108
	(0.033)	(0.036)	(0.040)	(0.044)	(0.046)	(0.042)	
Second order polynomial							
Tribal2017	-0.323***	-0.319***	-0.313***	-0.309***	-0.305***	-0.320***	1.319
	(0.044)	(0.046)	(0.047)	(0.047)	(0.048)	(0.045)	
Third order polynomial							
Tribal2017	-0.316***	-0.312***	-0.309***	-0.304***	-0.289***	-0.323***	1.641
	(0.047)	(0.047)	(0.047)	(0.048)	(0.049)	(0.047)	
Fourth order polynomial							
Tribal2017	-0.309***	-0.304***	-0.301***	-0.298***	-0.303***	-0.312***	1.624
	(0.047)	(0.047)	(0.048)	(0.049)	(0.054)	(0.047)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(4197/2566)	(3775/2565)	(3317/2560)	(2834/2547)	(2216/2510)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A3-6 Fuzzy RD Results of High-value Crops Rate (CDL dataset)

Sample Within	High-value Crops Rate						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Tribal2017	-0.140***	-0.142***	-0.144***	-0.147***	-0.143***	-0.144***	0.820
	(0.018)	(0.020)	(0.021)	(0.024)	(0.026)	(0.023)	
Second order polynomial							
Tribal2017	-0.147***	-0.147***	-0.147***	-0.143***	-0.144***	-0.153***	1.316
	(0.024)	(0.025)	(0.026)	(0.026)	(0.027)	(0.026)	
Third order polynomial							
Tribal2017	-0.149***	-0.148***	-0.145***	-0.142***	-0.150***	-0.144***	2.072
	(0.026)	(0.026)	(0.027)	(0.027)	(0.028)	(0.024)	
Fourth order polynomial							
Tribal2017	-0.148***	-0.144***	-0.144***	-0.157***	-0.173***	-0.150***	2.515
	(0.027)	(0.027)	(0.028)	(0.028)	(0.030)	(0.026)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(5905/4879)	(5318/4826)	(4649/4744)	(3921/4646)	(3063/4467)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

Table A3-7 Fuzzy RD Results of High-value Crops Rate (WRL dataset)

Sample Within	High-value Crops Rate						
	<1.5 Miles	<1.25 Miles	<1 Miles	<0.75 Miles	<0.5 Miles	Optimal Bandwidth	
First order polynomial							Optimal Miles
Tribal2017	-0.027***	-0.034***	-0.039***	-0.044***	-0.044***	-0.045***	1.121
	(0.010)	(0.011)	(0.012)	(0.013)	(0.014)	(0.013)	
Second order polynomial							
Tribal2017	-0.043***	-0.044***	-0.045***	-0.044***	-0.042***	-0.044***	1.168
	(0.013)	(0.013)	(0.014)	(0.014)	(0.014)	(0.013)	
Third order polynomial							
Tribal2017	-0.047***	-0.047***	-0.047***	-0.043***	-0.040***	-0.048***	1.443
	(0.014)	(0.014)	(0.014)	(0.015)	(0.015)	(0.014)	
Fourth order polynomial							
Tribal2017	-0.046***	-0.046***	-0.043***	-0.044***	-0.048***	-0.048***	1.772
	(0.014)	(0.014)	(0.015)	(0.015)	(0.018)	(0.014)	
Control Variables							
Townships	√	√	√	√	√	√	
Elevation	√	√	√	√	√	√	
Soil Productivity	√	√	√	√	√	√	
Observations (out/in)	(4954/3540)	(4462/3531)	(3922/3505)	(3345/3470)	(2603/3399)		

Notes: Coefficients significantly different from zero are denoted by the following system: * 10%, ** 5%, and *** 1%. Robust standard errors are provided in the parenthesis.

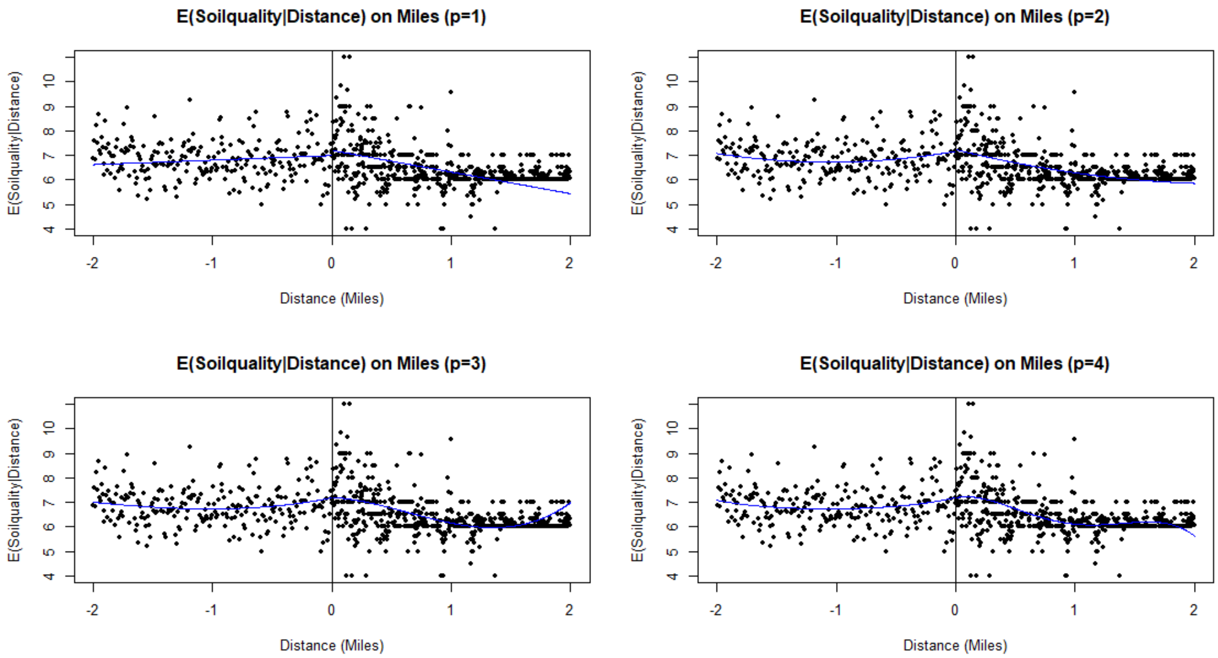

Fig A1-1 – RD plots of soil quality with 1st, 2nd, 3rd, and 4th order polynomial using 1905 Allotment Boundary.

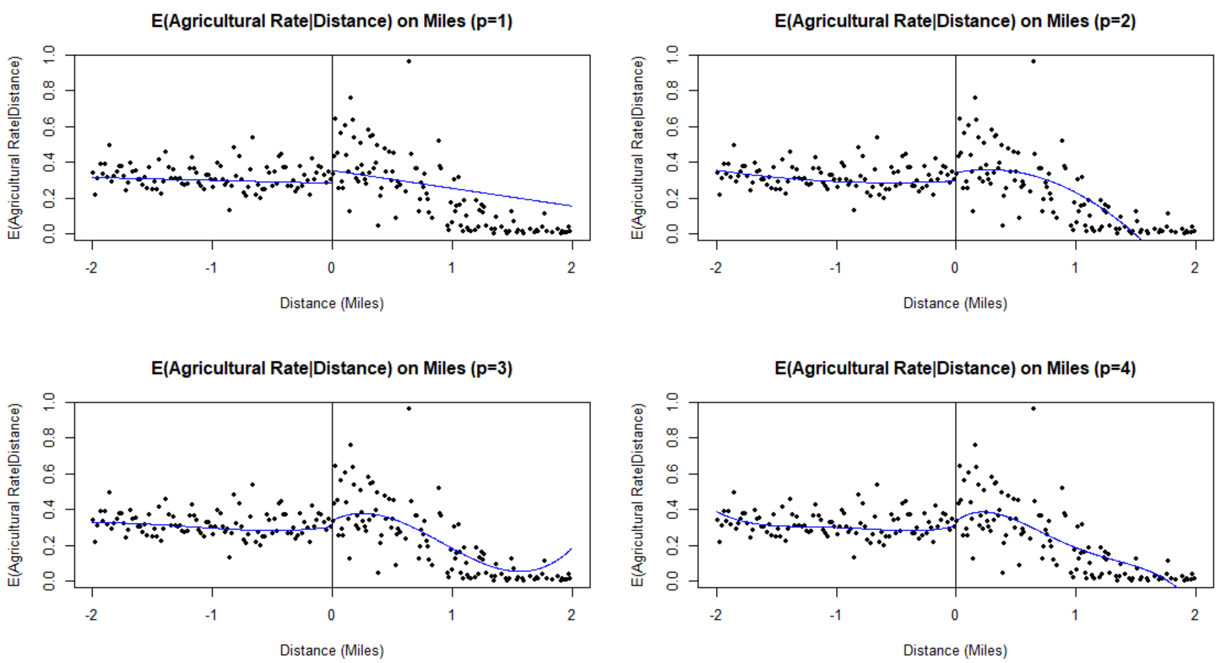

Fig A1-2 – RD plots of agricultural rate with 1st, 2nd, 3rd, and 4th order polynomial using 1905 Allotment Boundary using WRL dataset.

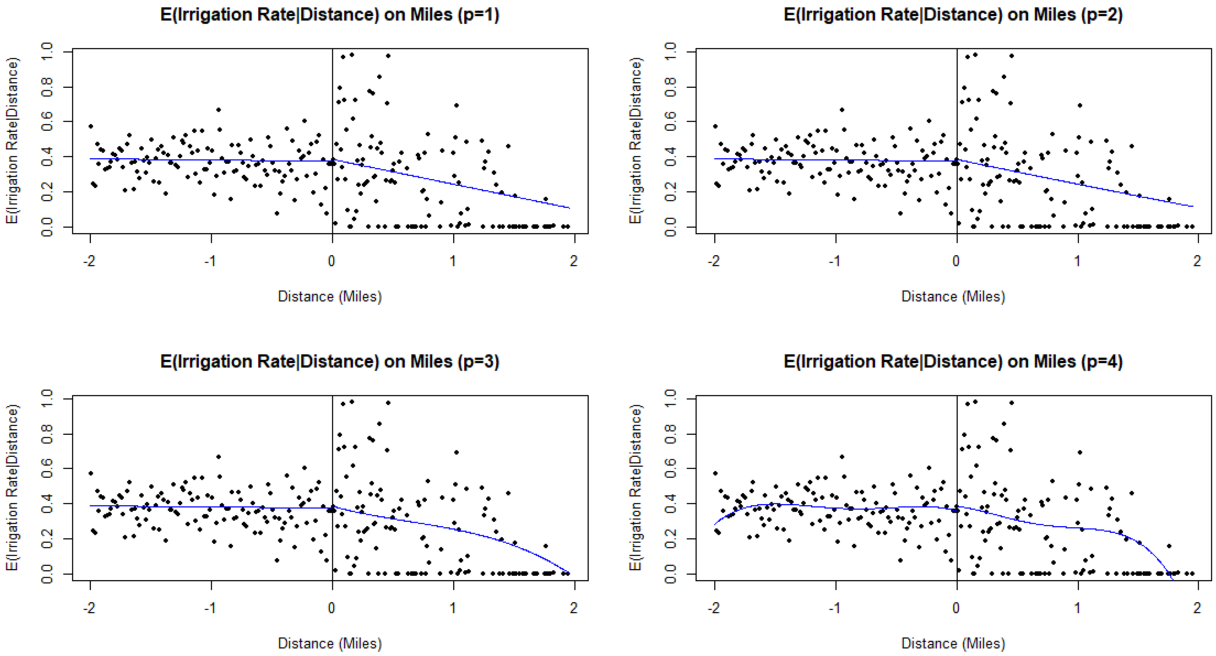

Fig A1-3 – RD plots of irrigation rate with 1st, 2nd, 3rd, and 4th order polynomial using 1905 Allotment Boundary.

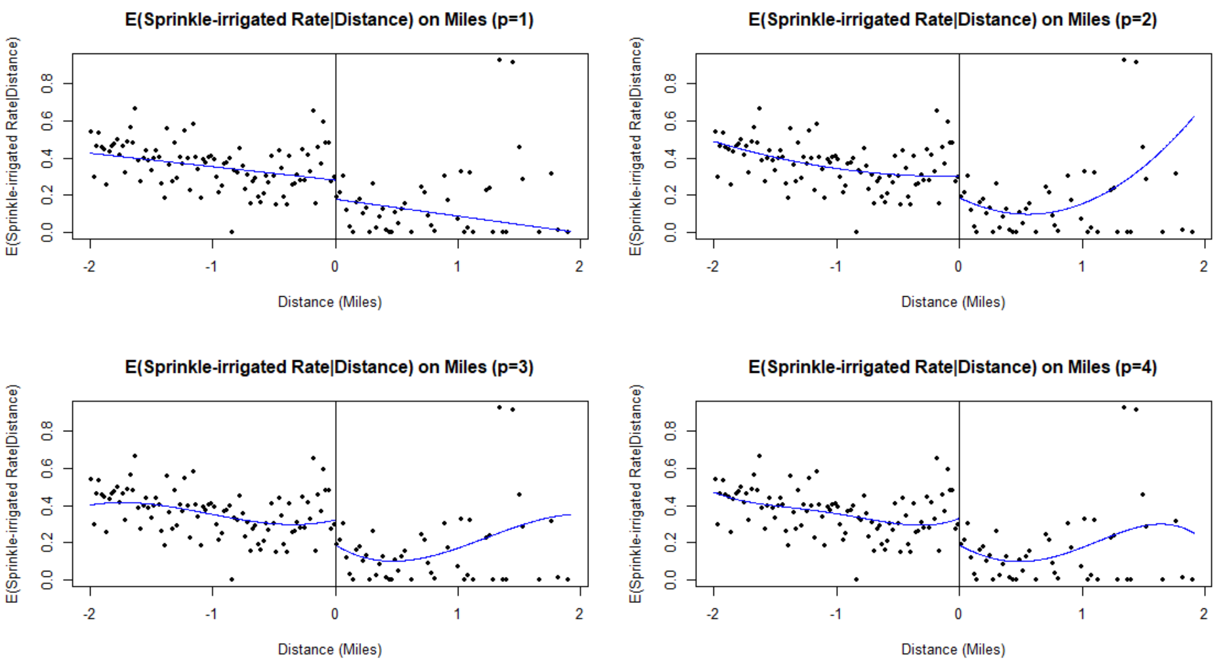

Fig A1-4 – RD plots of sprinkler-irrigated rate with 1st, 2nd, 3rd, and 4th order polynomial using 1905 Allotment Bundary.

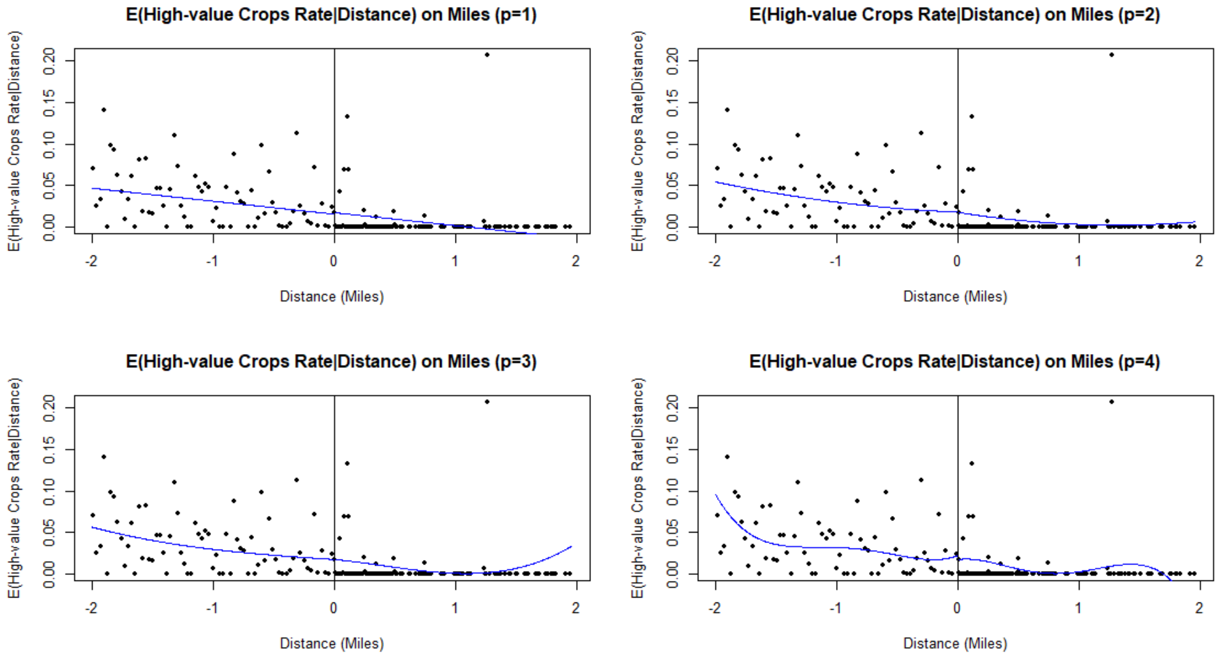

Fig A1-5 – RD plots of high-value crops rate with 1st, 2nd, 3rd, and 4th order polynomial using 1905 Allotment Boundary using WRL dataset.

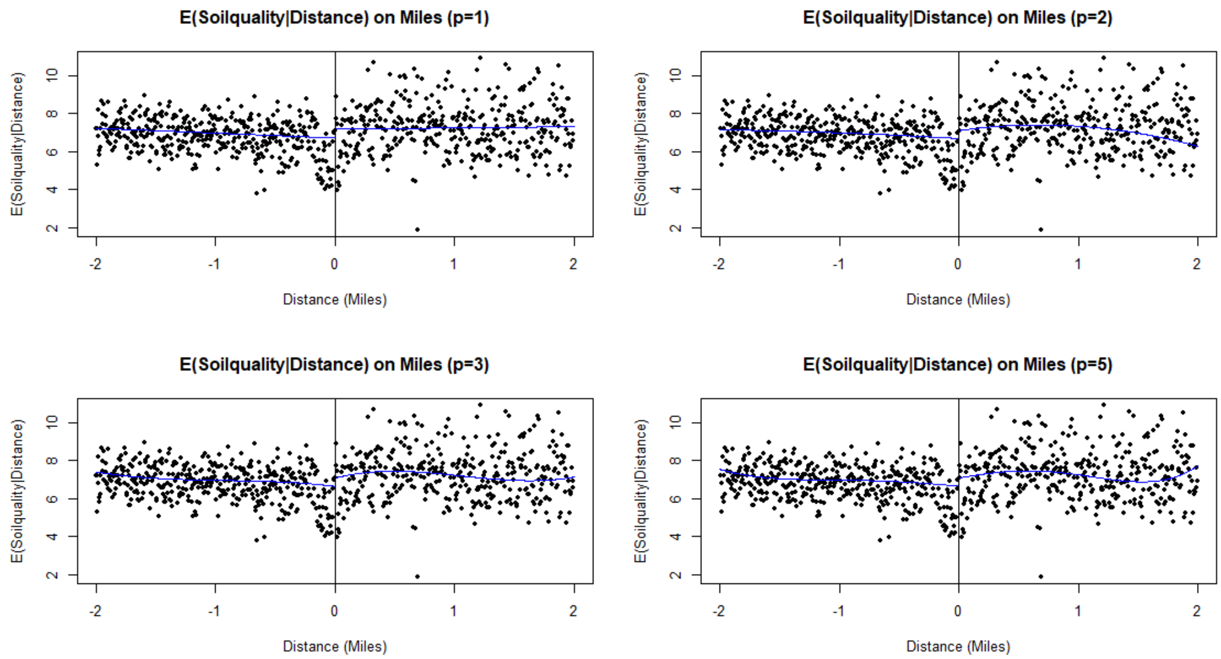

Fig A2-1 – RD plots of soil quality with 1st, 2nd, 3rd, and 4th order polynomial using 2017 Tribal Boundary.

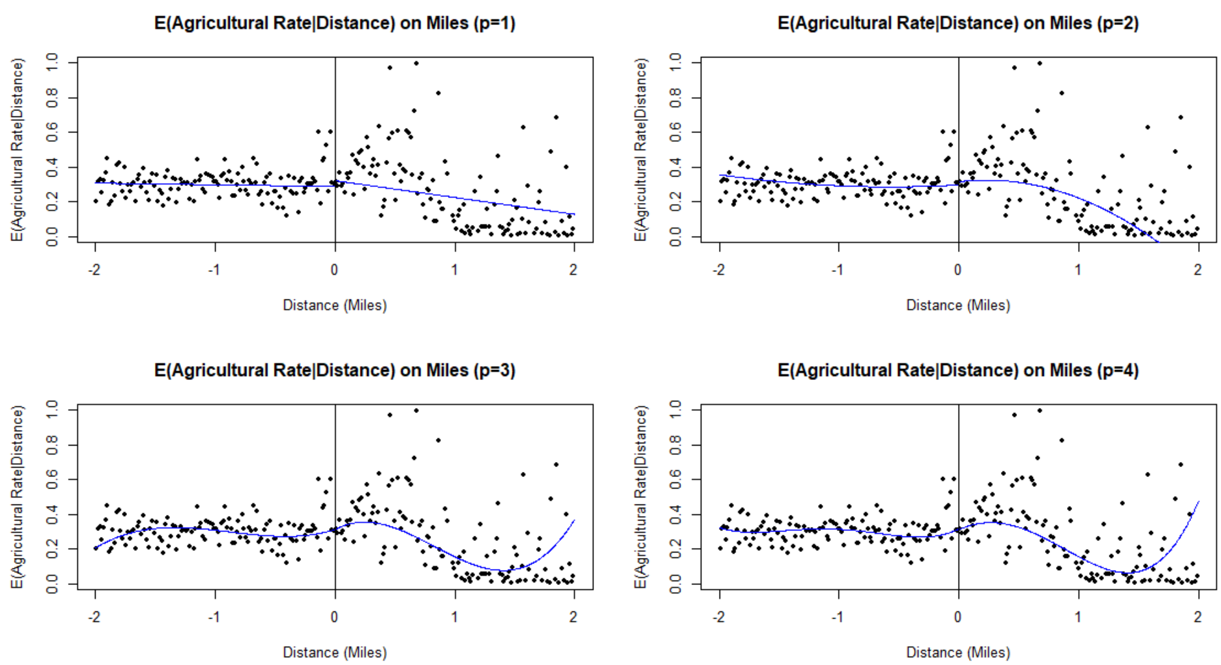

Fig A2-2 – RD plots of agricultural rate with 1st, 2nd, 3rd, and 4th order polynomial using 2017 Tribal Boundary using WRL dataset.

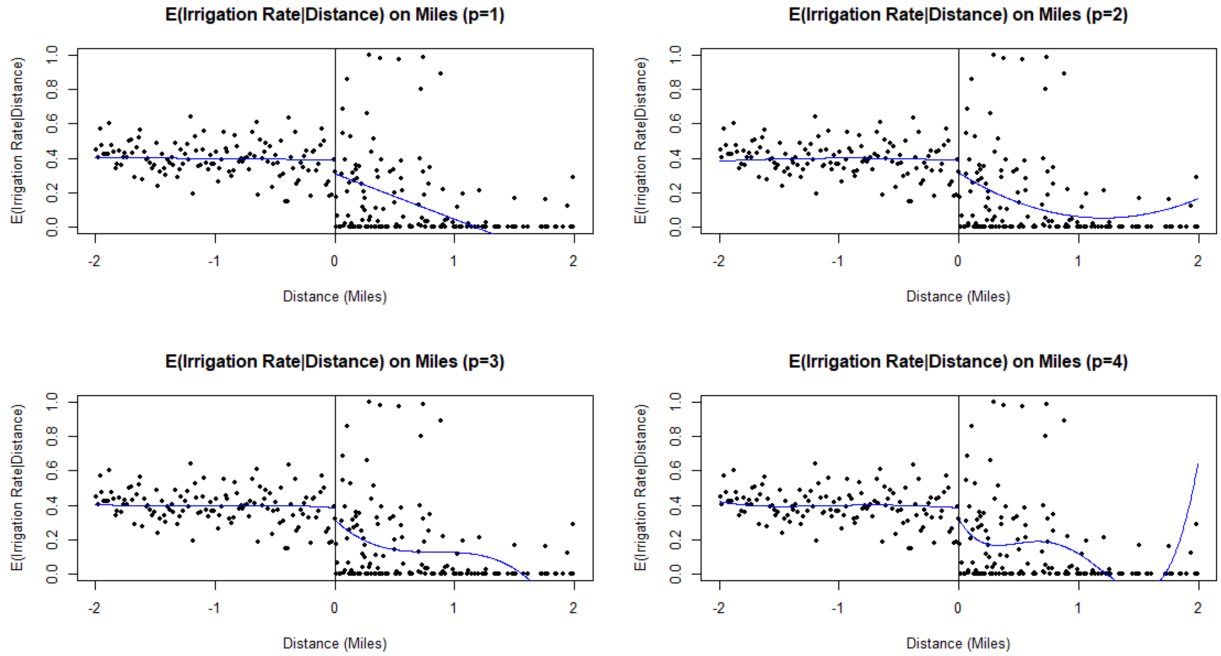

Fig A2-3 – RD plots of irrigation rate with 1st, 2nd, 3rd, and 4th order polynomial using 2017 Tribal Boundary.

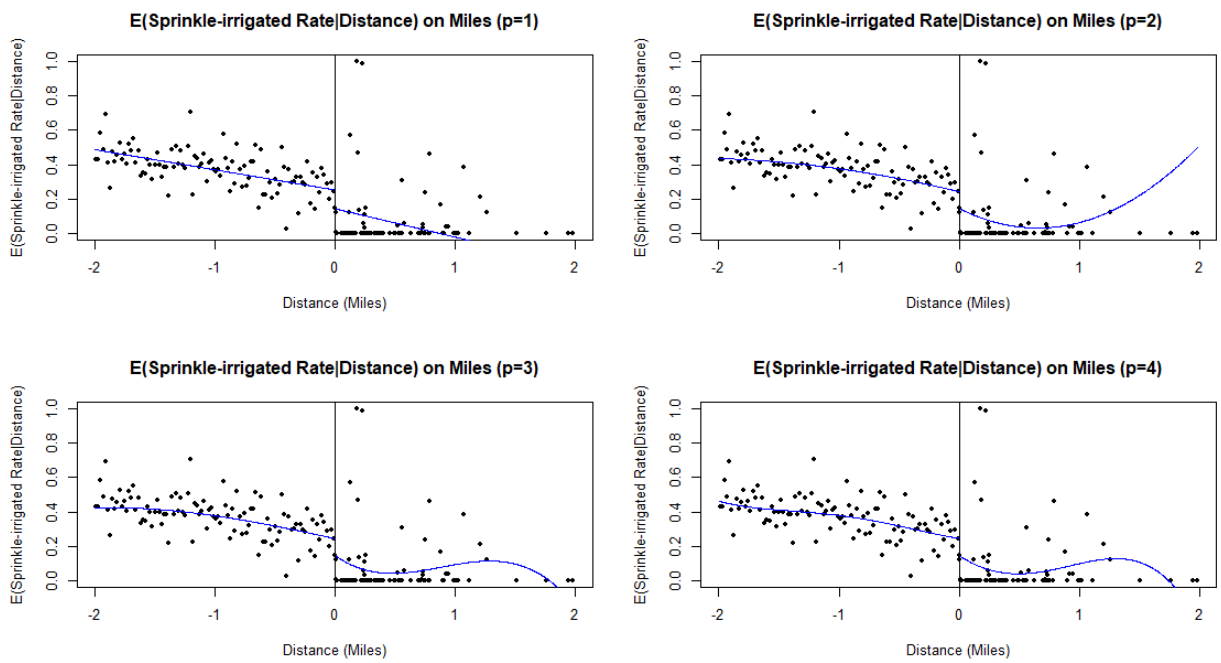

Fig A2-4 – RD plots of sprinkler-irrigated rate with 1st, 2nd, 3rd, and 4th order polynomial using 2017 Tribal Boundary.

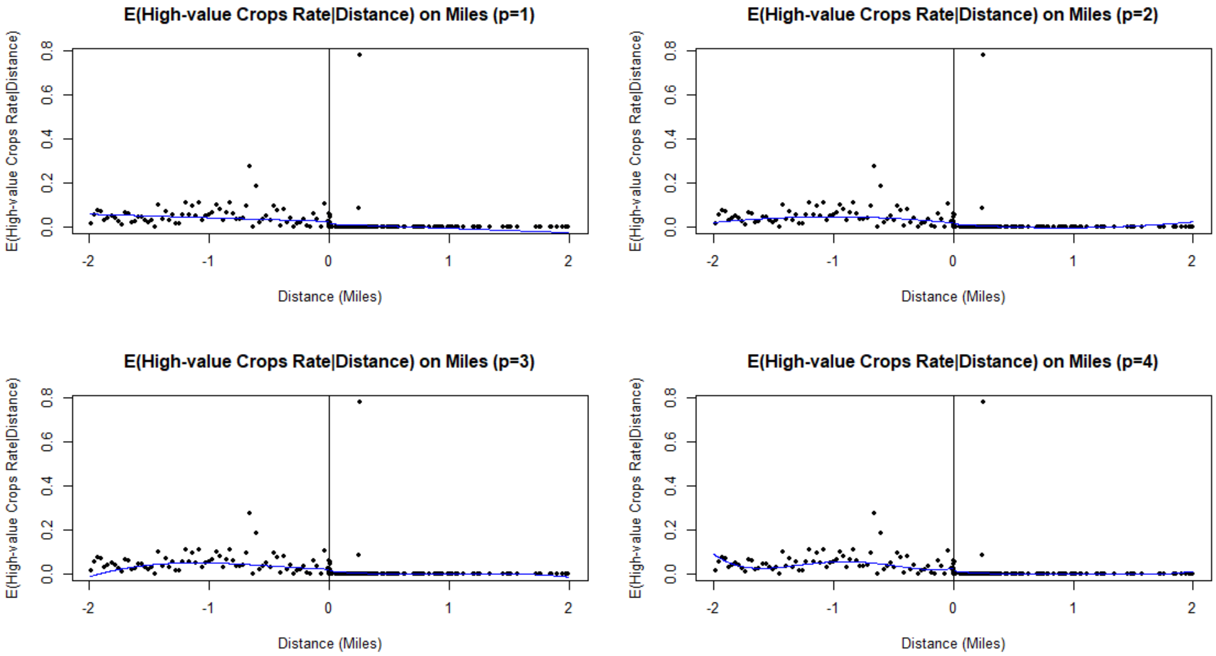

Fig A2-5 – RD plots of high-value crops rate with 1st, 2nd, 3rd, and 4th order polynomial using 2017 Tribal Boundary using WRL dataset.