A Appendix A

Table A1: Bison Herds Information

Herds ID	Wild (True =1, False =0)	County	State	HERD	Est year
1	0	Logan	KS	Smoky Valley Ranch	1860
2	1	Davis	UT	Antelope Island State Park	1893
3	0	Hot Springs	WY	Hot Springs State Park-Display herd	1896
4	1	Comanche	OK	Wichita Mountains National Wildlife Refuge	1907
5	1	Lake	MT	National Bison Range	1909
5	1	Sanders	MT	National Bison Range	1909
6	1	Cherry	NE	Fort Niobrara National Wildlife Refuge	1913
7	1	Custer	SD	Custer State Park	1913
8	1	Custer	SD	Wind Cave National Park	1913
9	0	Jefferson	CO	Genesee Park	1914
10	1	Fremont	Idaho	Yellowstone National Park	1918
10	1	Gallatin	MT	Yellowstone National Park	1918
10	1	Park	MT	Yellowstone National Park	1918
10	1	Park	WY	Yellowstone National Park	1918
10	1	Teton	WY	Yellowstone National Park	1918
11	0	Benson	ND	Sullys Hill National Game Preserve-too small	1918
12	1	Coconino	AZ	House Rock State Wildlife Area-Grand Canyon NP	1920
13	0	Murray	OK	Chickasaw NPS	1920
14	0	Los Angeles	CA	Santa Catalina Island	1924
15	1	Southeast Fairbanks	AK	Delta Junction	1928
16	1	Big Horn	MT	Crow Tribe	1930
16	1	Rosebud	MT	Crow Tribe	1930
16	1	Treasure	MT	Crow Tribe	1930
16	1	Yellowstone	MT	Crow Tribe	1930
16	1	Carbon	MT	Crow Tribe	1930
17	0	Douglas	CO	Daniels Park	1939
18	1	Garfield	UT	Henry Mountains	1941
19	0	Coconino	AZ	Raymond State Wildlife Area	1945
20	1	Dawes	NE	Fort Robinson State Park	1947
20	1	Sioux	NE	Fort Robinson State Park	1947
21	1	Teton	WY	Grand Teton National Park/Nat. Elk Refuge	1948
22	1	Valdez–Cordova	AK	Copper River	1950
23	0	Aleutians East Borough	AK	Popof Island-Unique island	1955
24	1	Billings	ND	Theodore Roosevelt National Park	1956
24	1	Mckenzie	ND	Theodore Roosevelt National Park	1956
25	1	Jackson	SD	Badlands National Park	1960
25	1	Pennington	SD	Badlands National Park	1960
25	1	Oglala Lakota	SD	Badlands National Park	1960
26	1	Valdez–Cordova	AK	Chitina	1962
27	1	Yukon-Koyukuk	AK	Farewell Lake	1965
28	0	San Diego	CA	Camp Pendelton	1969
29	1	Brown	NE	Niobrara Valley Preserve	1985
29	1	Keya Paha	NE	Niobrara Valley Preserve	1985
30	0	Brown	SD	Ordway Preserve-TNC	1985
31	1	Grand County	UT	UTE Tribal-Book cliffs	1986
32	0	Oliver	ND	Cross Ranch State Park	1986
33	0	Geary	KS	Konza Prairie Biological Station	1987
34	0	Jasper	Iowa	Neal Smith NWRF-too small	1990
35	0	Uinta	WY	Bear River State Park	1991
36	0	Colfax	New Mexico	Maxwell Wildlife Refuge	1992
37	0	Osage	Oklahoma	Tallgrass Prairie Preserve	1993
38	0	Briscoe	Taxes	Caprock Canyons-Southern herd	1994
39	1	Alamosa	CO	Medano-Zapata Ranch	1999
40	0	Hunt	Taxes	Clymer Meadow Preserve	1999
41	1	Fergus	MT	American Praire Reserve	2005
41	1	Phillips	MT	American Praire Reserve	2005
42	0	Custer	SD	Lame Johnny CreekSlim Buttes Project herd)-TNC	2005
43	1	Adams	CO	Rocky Mountain Arsenal	2007
44	0	Plymouth	Iowa	Broken Kettle-TNC-Grazing tool	2008
45	0	Hidalgo	New Mexico	Janos Hidalgo-Few wild animals left	2009
46	0	Chase	KS	Tallgrass Prairie Natl. Preserve	2009
47	0	Harrison	Missouri	Dunn Ranch TNC	2011
48	1	Blaine	MT	Fort Belknap Reservation	2012
49	1	Daniels	MT	Fort Peck Indian Reservation	2012
49	1	Roosevelt	MT	Fort Peck Indian Reservation	2012
49	1	Sheridan	MT	Fort Peck Indian Reservation	2012
49	1	Valley	MT	Fort Peck Indian Reservation	2012
50	0	Lee	IL	Nachusa Tallgrass PreserveTNC	2014
51	0	Will	IL	Midewin Refuge	2015
52	0	Larimer	CO	Laramie Foothills	2015
53	1	Glacier	MT	Blackfeet Reservation	2018
53	1	Pondera	MT	Blackfeet Reservation	2018

B Appendix B: DID with Propensity Score Matching

We select 30 counties with bison herds established between 1970 and 2018 in the treatment group and conduct the staggered DID using a pre-matched sample constructed by Propensity Score Matching (PSM). The matched sample is constructed using one to five NN matching with 0.003 caliper.[10] We use covariates that are unaffected by treatment or more likely to be fixed over time for matching. Such covariates include outcome variables in the year 1969, mean temperature and perception in the year 1969, elevation, the percentage of land that are grasslands and shrubs in 2001.[11] Replacement is allowed in the matching process to reduce bias.

Table B1 shows the effects of bison reintroduction on income per capita, population density, and the total number of jobs based on the pre-matched sample constructed by the PSM. All outcomes are log-transformed, and standard errors are computed using the multiplier bootstrap. Results show that bison reintroduction reduces income per capita by 0.482%, population density by 6.8%, and the total number of jobs by 5.8%. The estimated impacts on income is insignificant, while the effects of bison reintroduction on jobs and population density are significant at 10%.

We graphically identify if the parallel trend assumption is satisfied based on Figure B1, Figure B2, and Figure B3. The estimated coefficients in Figure B1 to B3 show the average effects of bison reintroduction on a lag or lead before and after herds were established for the outcome variables income per capita, population density, and total number of jobs respectively. Year 0 represents the time period that a bison herd was established.The average effects are not significantly different from 0 before herds establishment, implying that the parallel trends assumption is satisfied.

[10]The caliper is selected based on the standard deviation (SD) of propensity scores. We calculated the caliper as 0.25*SD (Rosenbaum and Rubin, 1985).

[11]We calculate grassland coverage using National Land Cover Database (NLCD) 2001. The year 2001 is the earliest available year for NLCD.

Tables and Figures

Table B1: The Effect of Bison Reintroduction: DID with PSM

	(1) Income Per Capita	(2) Population Density	(3) Total number of jobs
Bison	-0.00482	-0.068*	-0.058*
	(0.031)	(0.041)	(0.033)
N	8200	8200	8200

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: This table summarizes the effects of bison reintroduction on income per capita, the total number of jobs, and population density using DID with PSM matching. We select 30 counties with bison herds established between 1970 and 2018 in the treatment group and conduct the staggered DID on a pre-matched sample constructed by PSM.

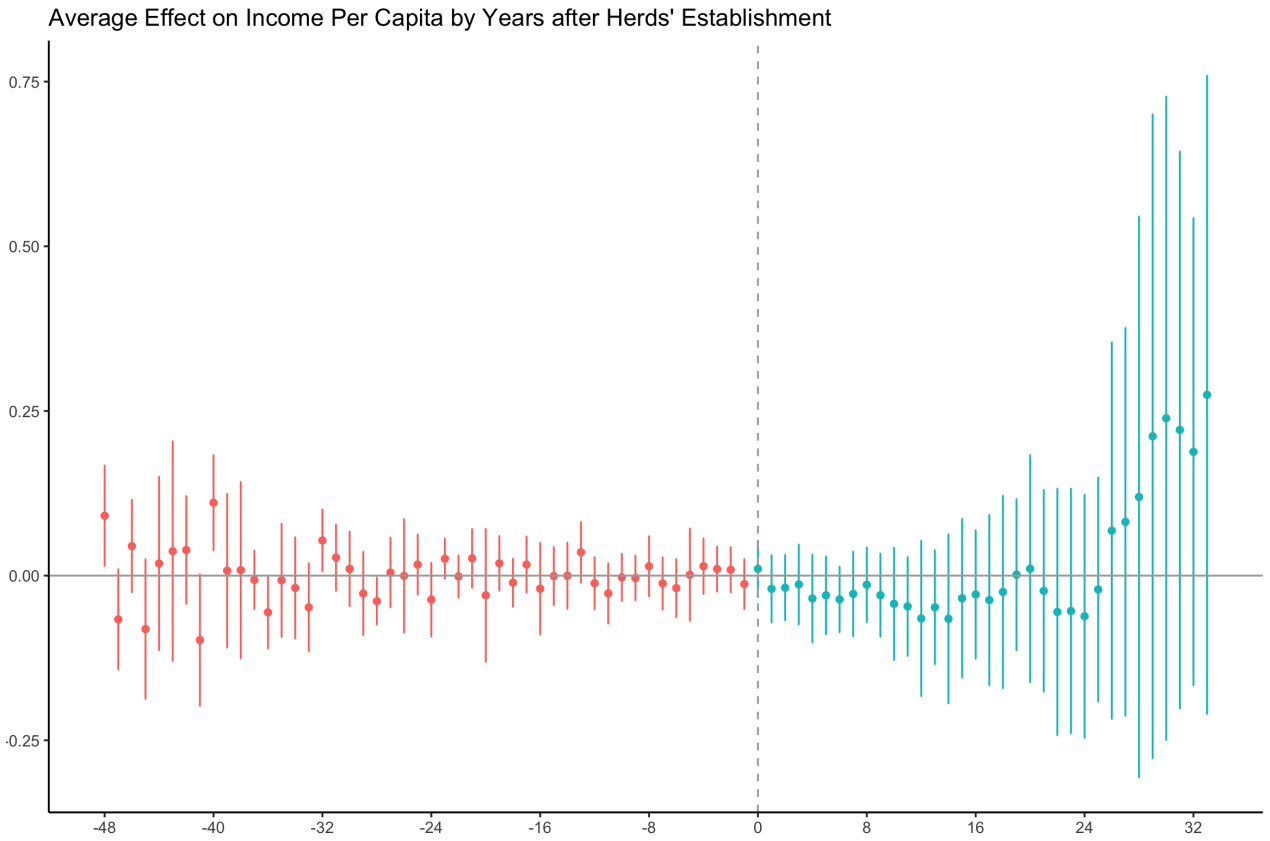

Figure B1: Average Effect on Income Per Capita by Years after Herds Establishment (PSM)

Note: This figure shows the average effects on income per capita across the different exposure lengths to the treatment. Results are estimated using DID with PSM matching. Year 0 represents the time period that a bison herd was established. The average effects are not significantly different from 0 before herds establishment, implying that the parallel assumption is satisfied.

Figure B2: Average Effect on the Total Number of Jobs by Years after Herds Establishment (PSM)

Note: This figure shows the average effects on the total number of jobs across the different exposure lengths to the treatment. Results are estimated using DID with PSM matching. Year 0 represents the time period that a bison herd was established. The average effects are not significantly different from 0 before herds establishment, implying that the parallel trend assumption is satisfied.

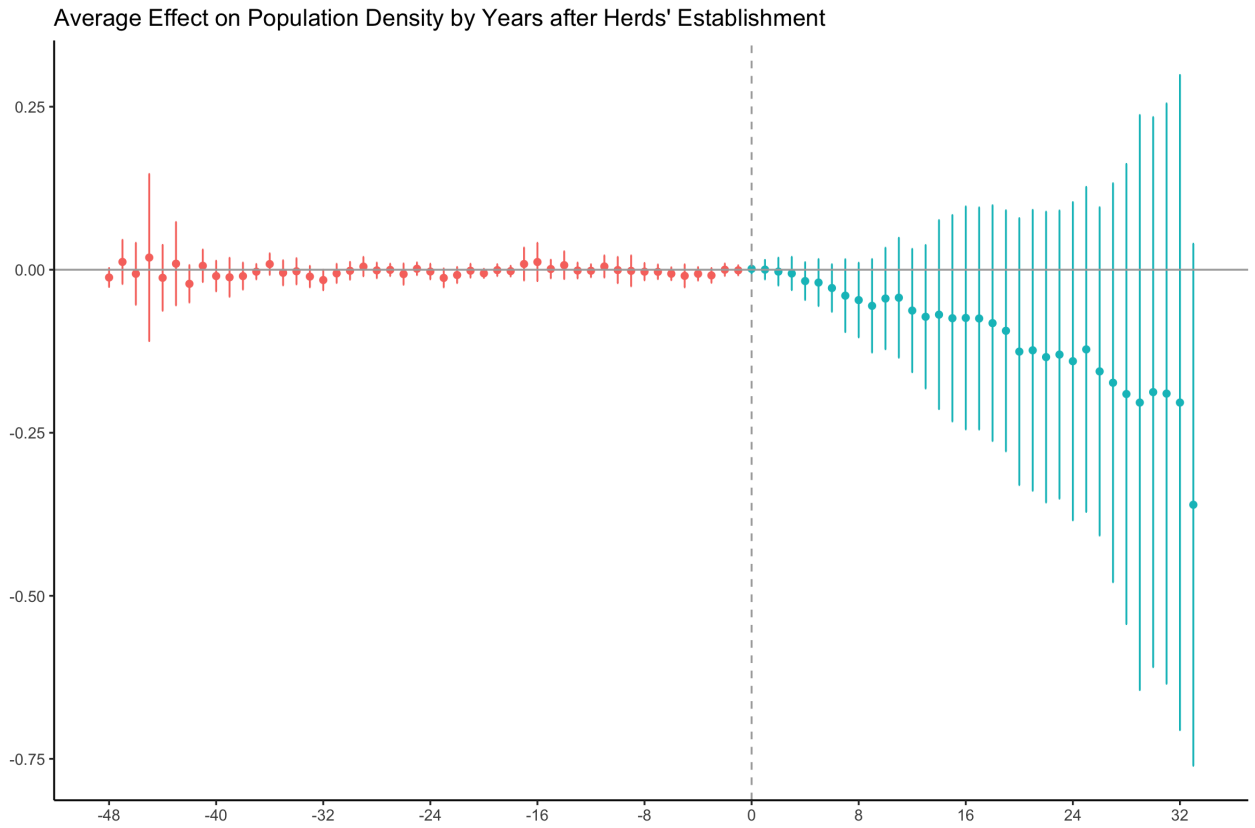

Figure B3: Average Effect on Population Density by Years after Herds Establishment (PSM)

Note: This figure shows the average effects on population density across the different exposure lengths to the treatment. Results are estimated using DID with PSM matching. Year 0 represents the time period that a bison herd was established. The average effects are not significantly different from 0 before herds establishment, implying that the parallel assumption is satisfied.

C Appendix C: Synthetic Control Results for Each Treated County

We focus on 16 counties with bison herds established between 1980 and 2005 as treated units and examine the impacts of bison reintroduction on local economic health for each treated counties using the SCM. For each treated unit, we choose 50 non-bison counties as potential controls in the donor pool. The donors are selected using the propensity score nearest neighbor matching (one to fifty). Propensity scores are calculated using data on observed county geographical and socio-economic characteristics—the same sets of covariates used to construct control groups in the DID with PSM approach. After conducting the nearest neighbor matching, we find paired matches for each treated county from the selected control units and use those paired matches as potential donors in SCM analysis.

We estimate the causal effects of bison reintroduction on per capita income, population, and the total number of jobs for each bison county. The blue lines in Figure C1 illustrate the actual time path of per capita income for treated counties, while the red lines illustrate the time path for synthetic controls. Similarly, Figure C2 and Figure C3 show the time path of the total number of jobs and population density for the treated and synthetic counties.

Visually assessing pre-treatment fit show that for some bison counties, the outcome paths of synthetic control during the pre-treatment period do not follow that of the treated unit. To formally evaluate the pre-treatment period goodness of fit of a synthetic county, we rank pre-treatment RMSPE in ascending order for treated counties among 50 donor units (Table C1). Counties with a pre-treatment RMSPE greater than the 70th percentile of the distribution of RMSPE in the donor pool are excluded to ensure a good pre-treatment fit. We refine the sample and include ten bison counties in the treatment group in the final results. These ten treated counties are categorized by the types of bison herds that have been established, which result in six counties with wild bison herds and four counties with non-wild bison herds. The counties that have wild bison herds include Alamosa, CO, Grand County, UT, Fergus, MT, Phillips, MT, Brown, NE, Keya Paha, NE, and the counties that have non-wild bison herds include Jasper, IA, Colfax, NM, Brown, SD, and Custer, SD.

After estimating the effects, we follow Abadie and Gardeazabal (2003) and Abadie et al. (2010) 's inference approach to determine the statistical significance of the estimated impacts, which is based on a placebo test. For each treated county, we assign the same bison herds establishment year as a placebo to its donors in the donor pool and apply the synthetic control method to every donor in our sample. Then we can graphically assess whether the treatment effect for the treated county is relatively large compared to the effects estimated for a county in the donor pool. If the difference between the treated county and its synthetic unit is larger than the difference for most of the placebo counties, it suggests that the bison reintroduction affects the outcomes. On the other hand, if multiple placebo units can produce "treatment" effects that are at least as large as those generated by the treatment counties, then it is likely that we observe the estimated treatment effect by chance.

Figure C4, C6, C5 present the estimated treatment effects and placebo test results of bison reintroduction on per capita income, population, and the total number of jobs for the counties with wild bison herds, while Figure C7, C9, C8 show the results for the counties with

nonwild bison herds. The solid black lines in these figures plot the yearly estimated impacts of bison reintroduction, which is the yearly gap in outcomes between the treated county and its synthetic county. We use placebo tests to evaluate the significance of our estimates. The gray lines show the difference between "treated" and synthetic units for the placebo tests applied to the control counties in the donor pool. If the distribution of placebo effects shows many effects as large as the main estimate, then it is likely that the estimated effect on a treated unit is observed by chance.

To formally evaluate the statistical significance of the estimated effects, following Abadie et al. (2010) and Abadie et al. (2015), we conduct the RMSPE test by calculating the post/pre RMSPE ratios and ranking ratios in descending order. A large ratio suggests that a treatment effect may exist. The p-values are obtained as the proportion of placebos that have a ratio of post-treatment RMSPE over pre-treatment RMSPE at least as large as the average ratio for the treated units. However, the p-values can be conservative if control units have both large pre and post RMSPE. To address this issue, we keep the control units during inference to those pre-treatment match quality no more than two times worse than the match quality of the corresponding treatment units (Abadie et al., 2010; Cavallo et al., 2013). We conduct the RMSPE test and compute p-values for each treated unit to assess the joint effect across all post-treatment periods. The p-values are interpreted as the proportion of placebos that have a ratio of post/pre RMSPE at least as large as the ratio for the treated units (Abadie et al., 2010, 2015). Results are presented in Table C2.

Using Alamosa county in Colorado as an example, the second graph in Figure C4 suggests that bison reintroduction in Alamosa county has a negative effect on per capita income. However, this negative effect is not robust to placebo tests, as many control units show similar or even larger income gaps. Given that Alamosa County is placed 17 out of 42 counties with a p-value of 0.4 (TableC2 Panel A), there is lack of significance of the treatment effect. The impact of bison reintroduction on the total number of jobs is negative (Figure C5) in Alamosa county. The RMSPE test points out that 9% of control units show similar or larger gaps than the treated county. Moreover, Figure C6 suggests that the estimated impact on population density is negative. However, 57% of control units show similar or larger gaps than the Alamosa county, indicating that the estimated effect is insignificant (TableC2 Panel C).

For both wild and nonwild bison herds, we do not observe consistent patterns of the impacts of bison reintroduction on per capita income (Figure C4 and C7). Establishing wild bison herds may have a negative impact on the total number of jobs (expect Fergus, MT) and population density (Figure C5 and C6. However, the impact of nonwild bison herds on local employment and population density can be positive or negative (Figure C8 and C9). Results in Table C2 suggest that bison reintroduction does not have a significant impact on per capita income, population, and local employment for both counties with wild and nonwild bison herds, which is consistent with the results we gain from DID matching.[12].

[12]Only the impact on per capita income is significant at 5% level in Keya Phah, NE

Tables and Figures

Table C1: Pre-treatment RMSPE Ranking

County fips	County	Income per capita	Total number of Jobs	Population density
8003	Alamosa,CO	28	23	34
8049	Grand County, UT	23	40	40
19099	Jasper, IA	6	20	30
20061	Geary,KS	20	43	44
30027	Fergus, MT	1	15	8
30071	Phillips, MT	29	17	9
31017	Brown,NE	30	28	14
31103	Keya Paha, NE	21	4	1
35007	Colfax, NM	9	29	6
38065	Oliver, ND	34	42	14
40113	Osage,Ok	40	35	22
46013	Brown,SD	13	30	31
46033	Custer, SD	10	31	28
48045	Briscoe, TX	39	20	37
48231	Hunt, TX	12	44	32
56041	Uinta, WY	6	48	49

Note: We rank pre-treatment RMSPE in ascending order for treated counties among 50 donor units. This table shows the ranking for each treated county for three outcome variables. Counties with a pre-treatment RMSPE greater than the 70th percentile of the distribution of RMSPE in the donor pool are excluded in the final analysis to ensure a good pre-treatment fit.

Table C2: RMSPE Tests

Panel A: Per capita income			
Bison County	Post/Pre RMSPE ratio	Treatment unit rank/# of All units	Percentage
Alamosa,CO	8.6	17 /42	40%
Grand County, UT	15.5	16 /39	41%
Jasper, IA	47.4	2 / 24	8%
Fergus, MT	6.8	5 / 11	45%
Phillips, MT	3.0	38 /45	84%
Brown,NE	5.7	37 /40	93%
Keya Paha, NE	37.5	2 / 38	5%
Oliver, ND	6.4	36 / 46	78%
Brown,SD	13.9	18 / 33	55%
Custer, SD	6.2	15 /27	56%
Panel B: Total number of jobs			
Bison County	Post/Pre RMSPE ratio	Treatment unit rank/ # of All units	Percentage
Alamosa,CO	12.0	3 /32	9%
Grand County, UT	37.0	7 / 43	16%
Jasper, IA	10.2	9 / 35	26%
Fergus, MT	4.6	7 / 28	25%
Phillips, MT	1.1	24 / 27	89%
Brown,NE	7.8	21 / 38	55%
Keya Paha, NE	6.4	11 / 16	69%
Oliver, ND	4.0	40 / 46	87%
Brown,SD	12.3	14 / 38	37%
Custer, SD	4.8	6 / 36	17%
Panel C: Population Density			
Bison County	Post/Pre RMSPE ratio	Treatment unit rank/ # of All units	Percentage
Alamosa,CO	2.4	23/ 40	57%
Grand County, UT	6.2	27/45	60%
Jasper, IA	3.3	27 / 40	68%
Fergus, MT	4.1	10 /24	42%
Phillips, MT	2.8	14 / 19	74%
Brown,NE	10.8	13 / 29	45%
Keya Paha, NE	19.4	3 / 10	30%
Oliver, ND	30.6	4 / 32	13%
Brown,SD	11.9	13 / 42	31%
Custer, SD	2.8	16 / 34	47%

Note: RMSPE test and compute p-values (Percentage) for each treated unit. The RMSPE test is conducted by calculating the post/pre RMSPE ratios and ranking ratios in descending order. A large ratio suggests that a treatment effect may exist.The p-values are interpreted as the proportion of placebos that have a ratio of post/pre RMSPE at least as large as the ratio for the treated units

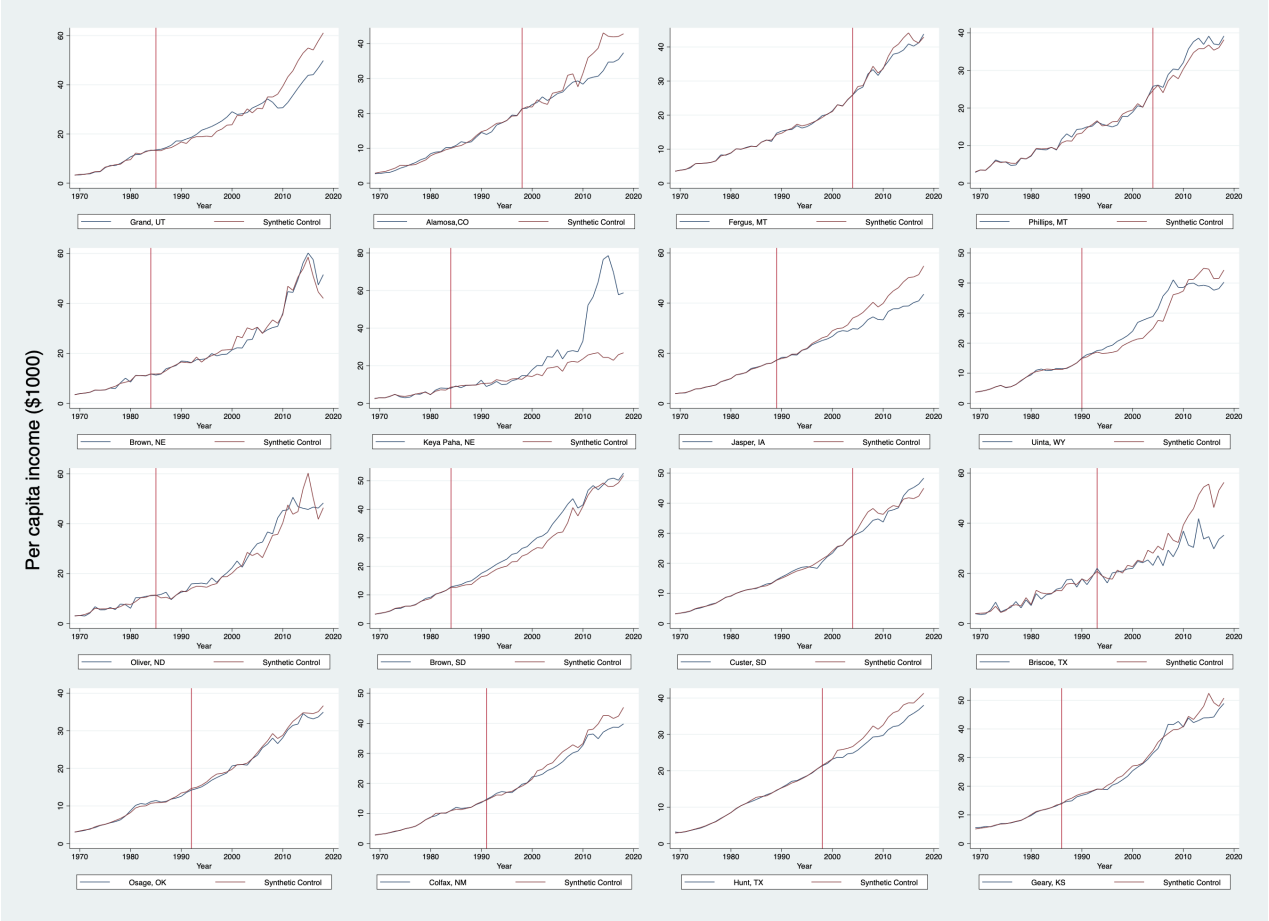

Figure C1: Income per capita between bison county and synthetic county

Note: This figure shows the time path of per capita income for the treated and synthetic counties. The blue lines illustrate the actual time path of per capita income for treated counties, while the red lines illustrate the time path for synthetic controls.

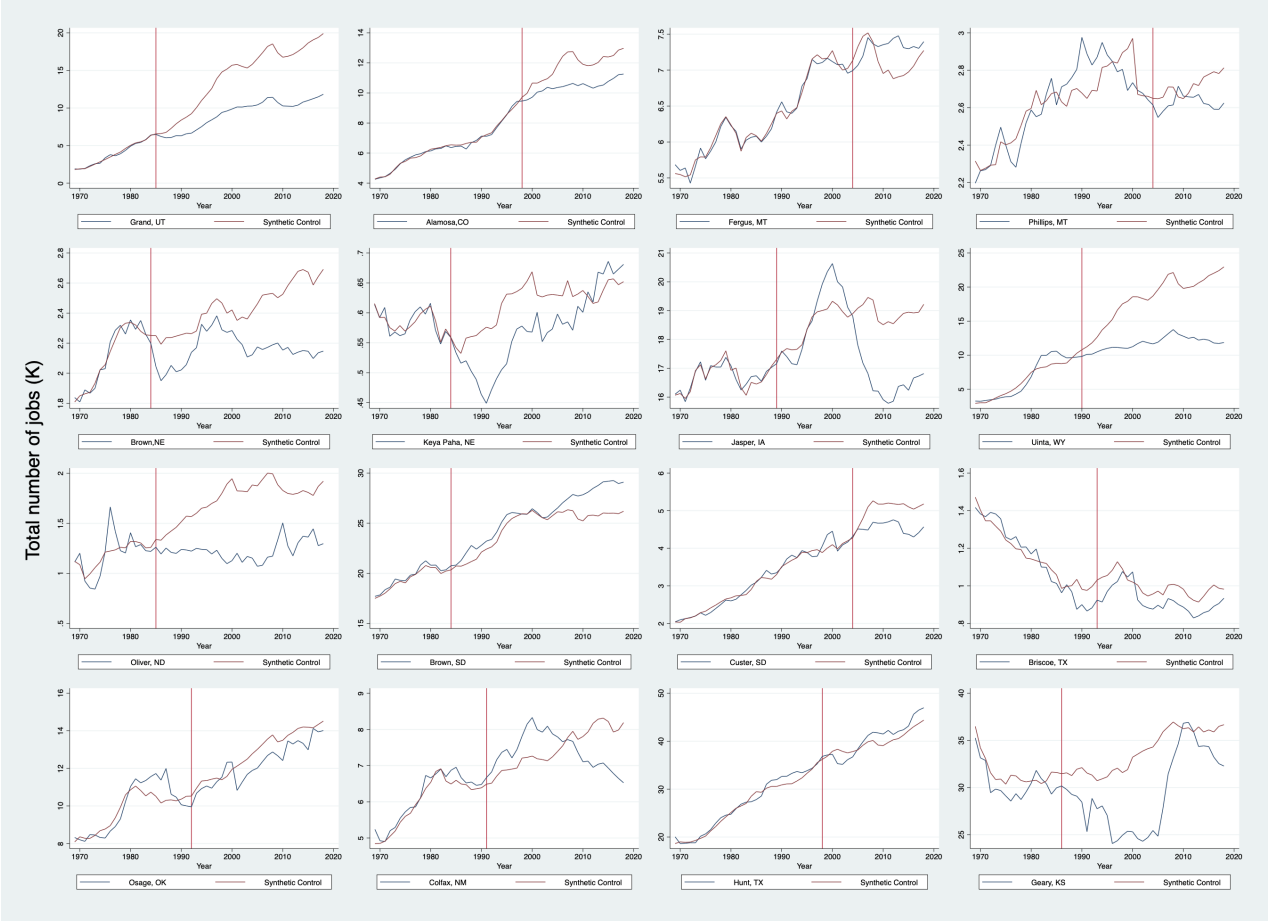

Figure C2: Total number of jobs between bison county and synthetic county

Note: This figure shows the time path of the total number of jobs for the treated and synthetic counties.The blue lines illustrate the actual time path of the total number of jobs for treated counties, while the red lines illustrate the time path for synthetic controls.

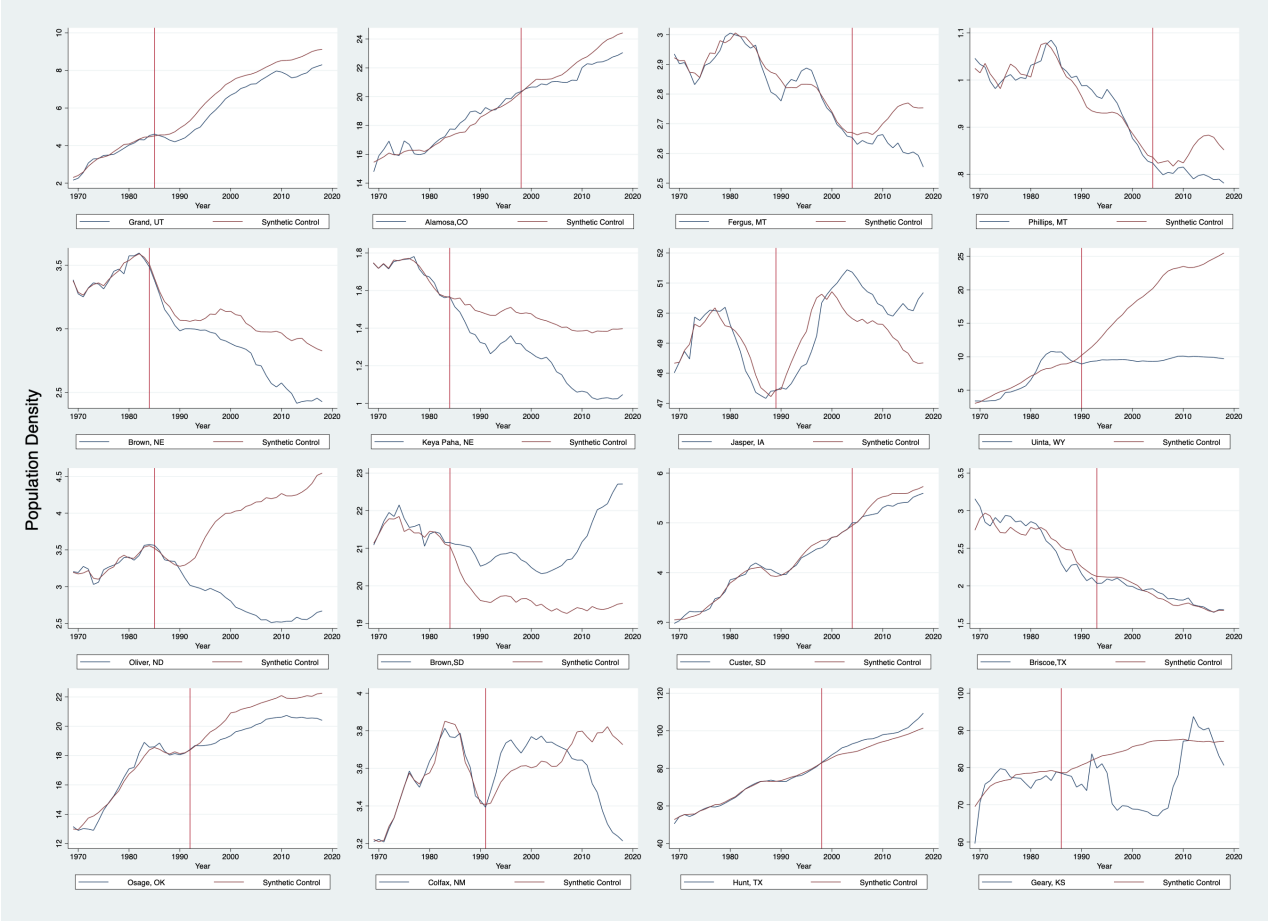

Figure C3: Population density between bison county and synthetic county

Note: This figure shows the time path of population density for the treated and synthetic counties.The blue lines illustrate the actual time path of population density for treated counties, while the red lines illustrate the time path for synthetic controls.

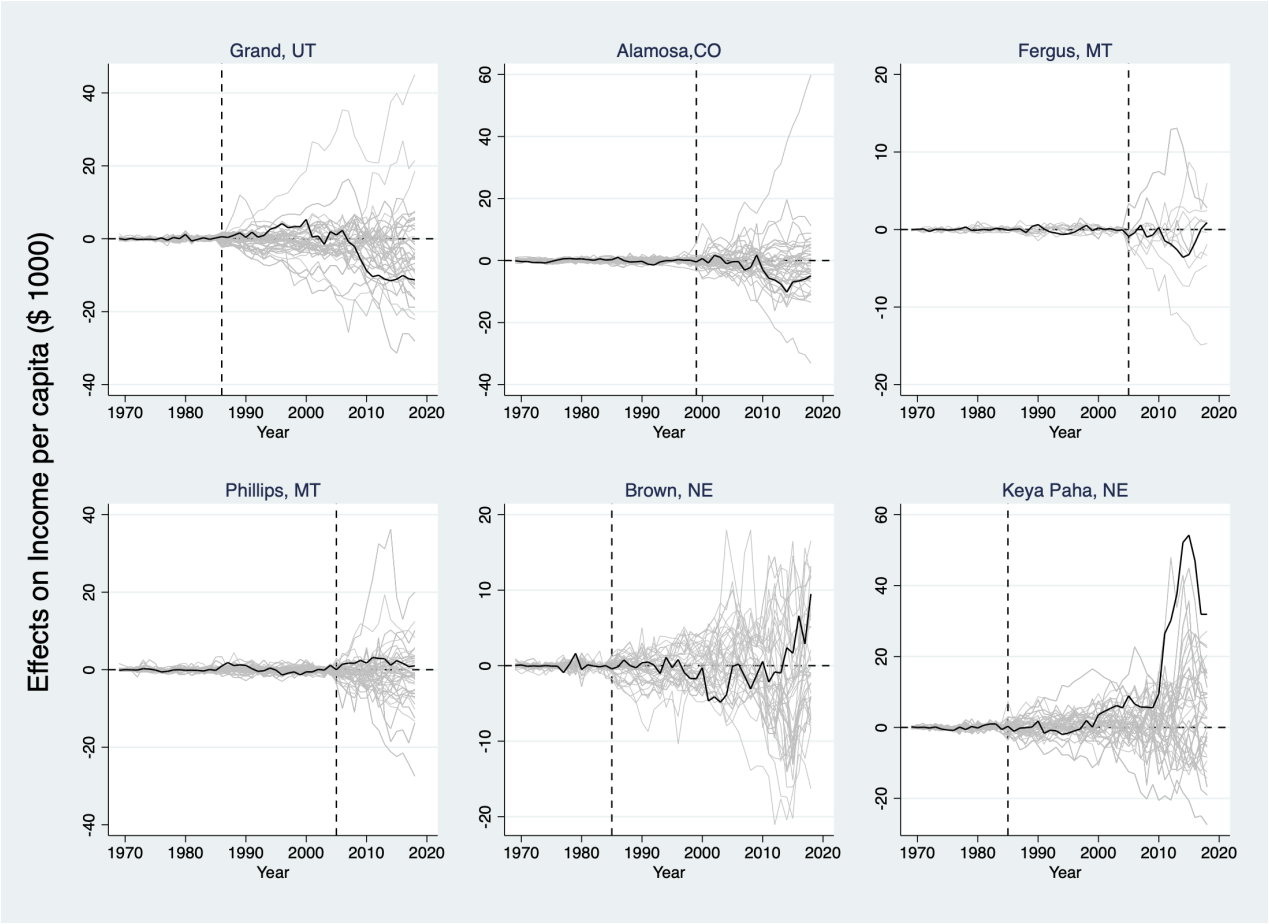

Figure C4: Counties with wild bison herds-Gaps in income per capita (Treated county vs control counties

Note: This figure shows the estimated treatment effects and placebo test results of bison reintroduction on per capita income. The solid black line plots the yearly gap in outcomes between the treated county and its synthetic county. The gray lines show the gaps for the placebo tests applied to the control counties.If the distribution of placebo effects shows many effects as large as the main estimate, then it is likely that the estimated effect on a treated unit is observed by chance. We limit the control units those with pre-treatment match quality no more than two times worse than the match quality of the corresponding treatment unit.

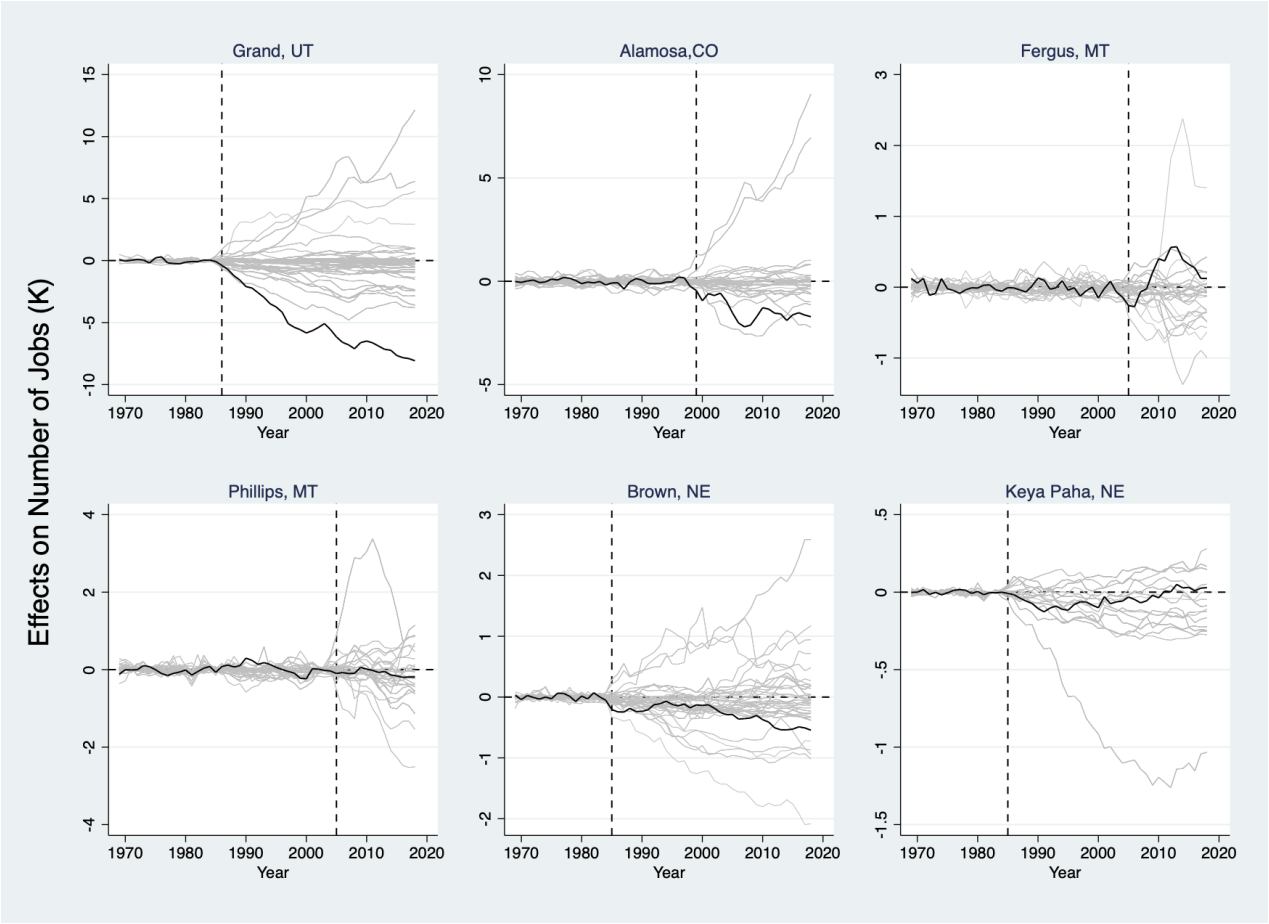

Figure C5: Counties with wild bison herds-Gaps in total number of jobs (Treated county vs control counties

Note: This figure shows the estimated treatment effects and placebo test results of bison reintroduction on employment. The solid black line plots the yearly gap in outcomes between the treated county and its synthetic county. The gray lines show the gaps for the placebo tests applied to the control counties.If the distribution of placebo effects shows many effects as large as the main estimate, then it is likely that the estimated effect on a treated unit is observed by chance. We limit the control units those with pre-treatment match quality no more than two times worse than the match quality of the corresponding treatment unit.

Figure C6: Counties with wild bison herds-Gaps in population density (Treated county vs control counties

Note: This figure shows the estimated treatment effects and placebo test results of bison reintroduction on population density. The solid black line plots the yearly gap in outcomes between the treated county and its synthetic county. The gray lines show the gaps for the placebo tests applied to the control counties.If the distribution of placebo effects shows many effects as large as the main estimate, then it is likely that the estimated effect on a treated unit is observed by chance. We limit the control units those with pre-treatment match quality no more than two times worse than the match quality of the corresponding treatment unit.

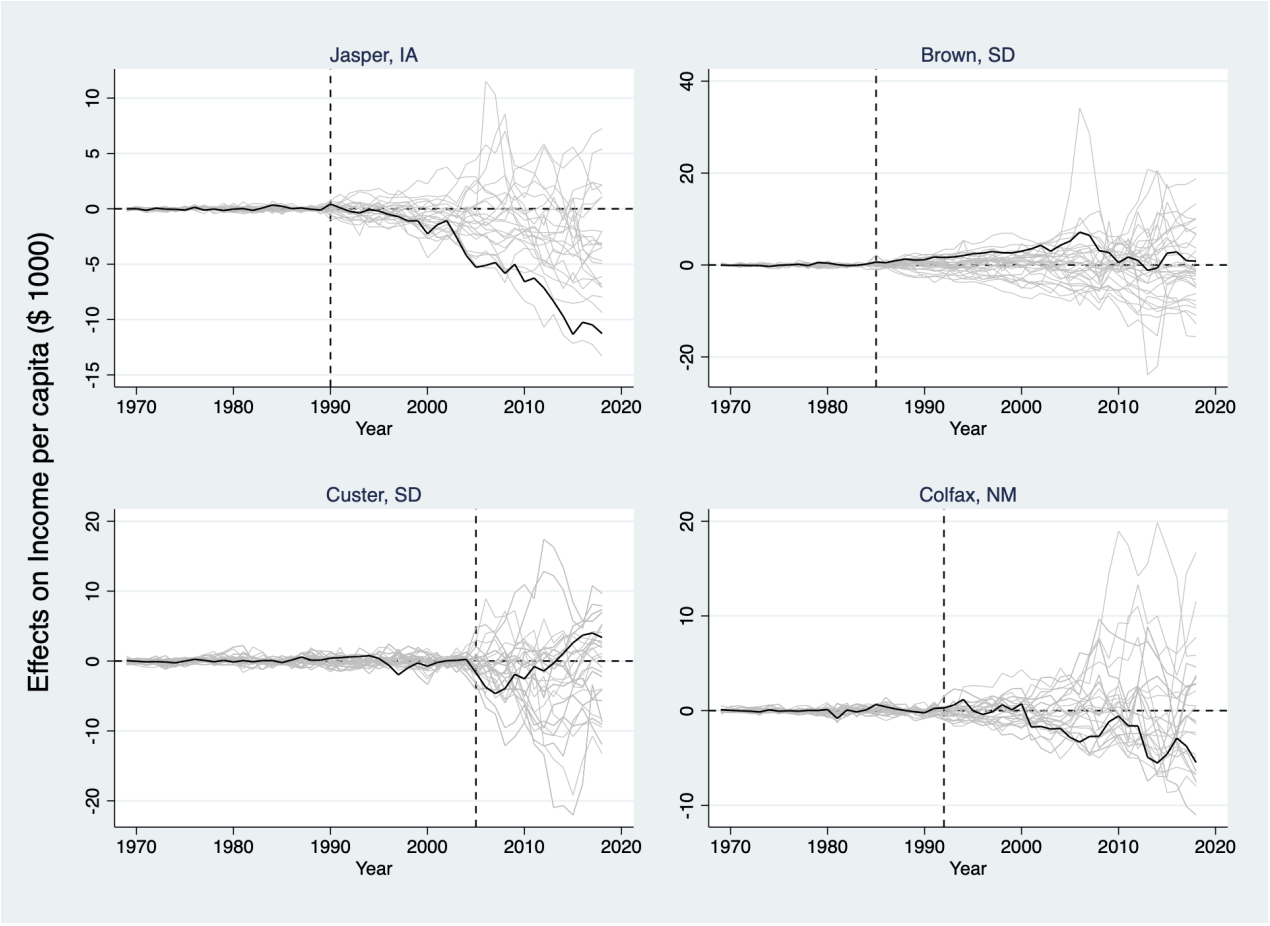

Figure C7: Counties with non-wild bison herds: Gaps in income per capita (Treated county vs control counties

Note: This figure shows the estimated treatment effects and placebo test results of bison reintroduction on income per capita. The solid black line plots the yearly gap in outcomes between the treated county and its synthetic county. The gray lines show the gaps for the placebo tests applied to the control counties.If the distribution of placebo effects shows many effects as large as the main estimate, then it is likely that the estimated effect on a treated unit is observed by chance. We limit the control units those with pre-treatment match quality no more than two times worse than the match quality of the corresponding treatment unit.

Figure C8: Counties with non-wild bison herds-Gaps in total number of jobs (Treated county vs control counties

Note: This figure shows the estimated treatment effects and placebo test results of bison reintroduction on employment . The solid black line plots the yearly gap in outcomes between the treated county and its synthetic county. The gray lines show the gaps for the placebo tests applied to the control counties.If the distribution of placebo effects shows many effects as large as the main estimate, then it is likely that the estimated effect on a treated unit is observed by chance. We limit the control units those with pre-treatment match quality no more than two times worse than the match quality of the corresponding treatment unit.

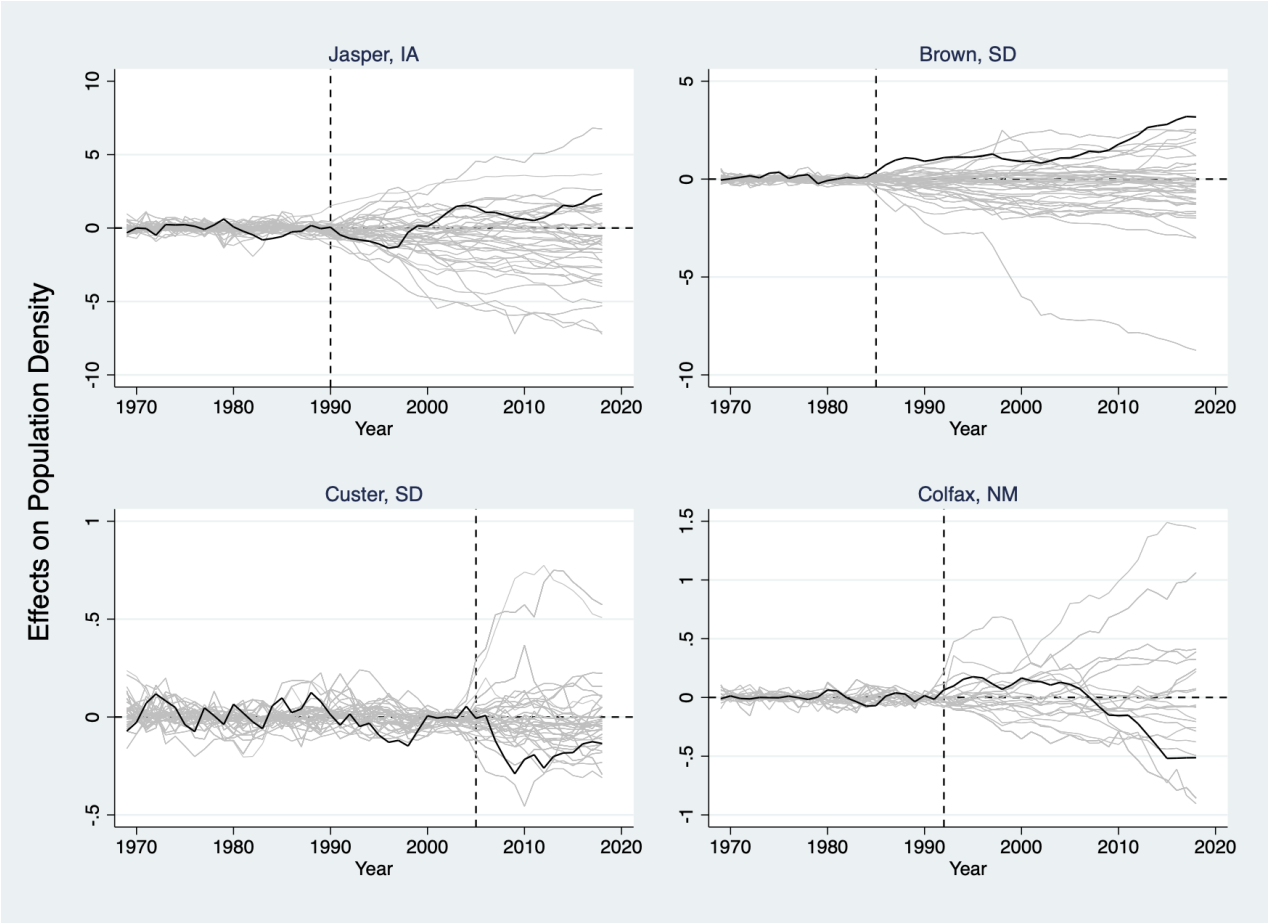

Figure C9: Counties with non-wild bison herds-Gaps in population density (Treated county vs control counties

Note: This figure shows the estimated treatment effects and placebo test results of bison reintroduction on population density. The solid black line plots the yearly gap in outcomes between the treated county and its synthetic county. The gray lines show the gaps for the placebo tests applied to the control counties.If the distribution of placebo effects shows many effects as large as the main estimate, then it is likely that the estimated effect on a treated unit is observed by chance. We limit the control units those with pre-treatment match quality no more than two times worse than the match quality of the corresponding treatment unit.