NAREA
NORTHEASTERN AGRICULTURAL AND
RESOURCE ECONOMICS ASSOCIATION

RESEARCH ARTICLE

The impact of bison reintroduction on local economies

Liqing Li[1]* and Amy W. Ando[2]

[1]Department of Economics, California State University Fullerton, Fullerton, CA, 92831, United States and
[2]Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign,
Champaign, IL, 62820, United States
*Corresponding author. Email: liqing@fullerton.edu

Abstract

Bison is an important and iconic mammal in the U.S. that is being reintroduced in many places after being driven nearly to extinction. This paper provides a nationwide assessment of the local economic impacts of bison reintroduction so that rural communities can take economic well-being into account when considering decisions regarding future bison restorations. We estimate the causal impacts of bison herd establishment on county-level income, employment, and population growth using staggered difference-in-difference and the synthetic control approaches. The simple positive correlation between local per capita income and bison herds might lead planners to think that bison reintroduction is good for the local economy. However, none of the causal inference analyses find statistically significant effects of bison reintroduction.

Introduction

The American bison is a charismatic mammal that is used to be a vital symbol and resource for Native Americans and helped shape grassland landscapes across North America. However, the American government and commercial interests nearly drove the bison to extinction in the late 19th century through over-hunting and habitat destruction (Taylor 2011). Government agencies and non-profit conservation groups are now restoring prairies and reintroducing bison to their historical range in an ongoing effort to bring this iconic mammal back from the brink of extinction in the wild (Zumbach 2015). However, the net economic impact of bison reintroduction on rural communities has not been studied (Emmet Jones et al. 2003). This paper informs debate over the likely economic effects of bison reintroduction with a nationwide assessment of the local economic impacts of bison reintroduction. We estimate the causal impacts of bison herd establishment on

county-level income, employment, and population growth so that rural communities can take economic well-being into account when considering their future decisions regarding bison restoration.

Currently, fifty-three bison herds exist in the U.S. These herds could have a range of effects on the people around then. Bison reintroduction could increase the attachment people have to grassland areas (Wilkins et al. 2019) and might improve the health of rural economies by increasing local tourism through wildlife marketing (Vasile 2018). However, farmers, ranchers, and local residents have expressed concerns regarding bison reintroduction. For example, the presence of bison could limit profitable use of cropland and rangeland re-purposed as bison habitat. Cattle ranchers worry about the potential for diseases like brucellosis to spread from bison to cattle, and rural leaders worry that bison establishment could be a step on the path to national monument designation, which might limit economic activity (Boyd and Gates 2006; Davenport 2018).

Economists have studied several dimensions of the relationship between conservation and local economies. One body of research on the effects of protecting nature on local economic activity has focused on land conservation. Some studies raised concern that protected areas could be a threat to local economic well-being (Rasker 1993) and that rapid growth in nature-based visitation could challenge local community resilience (Winter et al. 2020). However, other papers have suggested that protected areas can improve conditions in local economies. Increased tourism can in some cases provide more employment opportunities (Andam et al. 2008, 2010; Albers and Robinson 2013; Bode et al. 2015), increase income (Wunder 2000), and promote local business establishment and economic development (Walls et al. 2020). Work by Kennedy et al. (2016) showed that the economic effects of conservation depend critically on the scale and nature of the interventions, and other papers found that land conservation, as in the northern forest region of the U.S. (Lewis et al. 2002) or new large national monuments (Jakus and Akhundjanov 2019), has had no significant effects on local economies at all.

A body of work has also studied the local economic effects of wildlife conservation and restoration itself, with similarly mixed findings Langpap et al. 2020). Some papers showed that species conservation has negative effects on measure of local economic health like income, population, or employment (Lewis et al. 1990; Emerton 2001; Eichman et al. 2010; Ferris and Frank 2021). However, others found that species conservation can actually improve some dimensions of local economic activity and human well-being (Fernandez et al. 2009; Chen et al. 2016; Raynor et al. 2021).

Thus, previous research on the economic effects of wildlife conservation or restoration does not yield clear predictions for the likely impact of bison reintroduction in the U.S. In a hypothetical choice experiment study, Foelske et al. (2019) found that residents near bison herds in Illinois and Iowa actually had no preference for those herds either to grow or shrink in future scenarios of their communities. Research on other charismatic species implies bison reintroduction might drive increases in visitor expenditures and help local economies (Wilson and Tisdell 2003; Loomis and Caughlan 2004; Duffield et al. 2008). On the other hand, cattle ranchers have persistent fears that bison may reduce incomes by competing for rangeland with cattle, even though experimental research does not show that to be the case (Kohl et al. 2013). There has been no study of how bison reintroduction in grassland areas actually affects local economic well-being in the U.S. to show whether positive or negative effects have actually come to pass. This paper fills that gap.

We assemble a novel data set that includes information on each herd's name, location, type, size, and year of establishment for all 53 bison herds in the U.S. There are 66 counties in 19 states in the U.S. that have bison herds established between 1860 and 2018. We merge county-level data from the U.S. Bureau of Economic Analysis (BEA) on economic health

with the data on bison herds to study the impact of bison reintroduction on local economic development in the counties that host them.

A simple probit model shows the presence of bison herds in a county and is positively correlated with the county's per capita income. However, that correlation should not be interpreted as a causal link between bison and economic activity since bison are not randomly placed in the landscape, and many other factors could influence local economies. Thus, we use other methods – staggered difference-in-difference (DID) with multiple time periods and the synthetic control method (SCM) – to estimate the causal impact of bison reintroduction on local employment, population, and per capita income.

Similar to the results of Jakus and Akhundjanov (2019) described above, our causal inference analyses find little evidence of any significant impact of bison reintroduction on local economic activity, either positive or negative. Results from our DID analysis show that bison reintroduction has no significant impact on per capita income, the total number of jobs, or population density. Results from the SCM are consistent with the findings of the DID analysis; bison reintroduction has an insignificant impact on local economic health. Thus, the results of this study suggest that while bison reintroduction may not be a big local economic driver, it also does not undermine local economic health.

Empirical strategy

One could readily estimate the average treatment effect attributable to bison reintroduction if bison herds were randomly established in U.S. counties. However, since bison reintroduction happened in selective locations, it is challenging to identify the causal relationship between bison reintroduction and the local economy. This section presents the two causal inference methods we use to estimate the impact of bison reintroduction on local economic health: staggered DID and SCM.

DID with multiple time periods

Bison herds were established in different years across the landscape; thus, we adopt a staggered DID design with multiple treatment periods. A two-way fixed effects (TWFE) model is commonly applied in these circumstances. However, recent research documents potential shortcomings of this specification (Borusyak and Jaravel 2017; Callaway and Sant'Anna 2021; De Chaisemartin and d'Haultfoeuille 2020; Goodman-Bacon 2021) More specifically, a TWFE model with multiple treatment timing not only compares the newly treated county with never treated and not-yet treated counties but also compares newly treated counties with already treated units. The last comparison may bias the estimated treatment effect since the path of outcomes for already treated units includes treatment effect dynamics and cannot serve as a good control (Callaway and Sant'Anna 2021). To address this issue, we follow an alternative approach proposed by Callaway and Sant'Anna (2021), which only uses the desirable comparisons instead of all possible comparisons to estimate treatment effects.

Callaway and Sant'Anna (2021) first calculate the group-time average treatment effects $ATT(g, t)$, which is a unique ATT for a cohort of units treated at the same point in time. The group-time average treatment effects are estimated as follows:

$$ATT(g, t) = E[Y_t(g) - Y_t(0)|G = g] \tag{1}$$

where G is the time period when a county has bison herds established. Treatment counties are grouped based on the establishment years of bison herds. Once a county establishes a bison herd, it remains treated (staggered treatment adoption assumption). We restrict the

control group to be the group of counties that have not yet participated in the treatment in that time period, including all never-treated counties and additional counties that eventually establish bison herds but have not yet established.

Bison counties may be comparable to non-bison counties conditioning on observed pre-treatment covariates, X. We use these covariates to predict the conditional probability of being treated (have bison herds established). Observed pre-treatment covariates included in the analysis are county size, average precipitation, mean temperature, elevation, the percentage of land that are grasslands and shrubs in 2001, and whether the county is in a metropolitan area.[1] After conditioning on observed pre-treatment covariates, the conditional parallel trend assumption based on not-yet been treated units is given as follows.

For all $g = 2, \ldots G$; $s,t = 2,.,\tau$ with $t \geq g$ and $s \geq t$

$$E[Y_t(0) - Y_{t-1}(0)|X, G = g] = E[Y_t(0) - Y_{t-1}(0)|X, D_s = 0, G \neq g] \qquad (2)$$

Under this parallel trend assumption, we can use the not-yet-treated by time s ($s \geq t$) units as control groups when calculating the effect for the group that is first treated in time g. We estimate the group-time average treatment effects through doubly robust (DR) estimation procedure recommended by Callaway and Sant'Anna (2021) and Sant'Anna and Zhao (2020). The DR estimation combines outcome regression (OR) proposed by Heckman et al. (1997) and inverse probability weighting (IPW) estimators proposed by Abadie (2005) into one specification. The DR estimators share the strengths of OR and IPW because they can identify the ATT even if one of the two models (the propensity score model and the OR model) is misspecified (Sant'Anna and Zhao 2020).

After calculating $ATT(g, t)$, we follow Callaway and Sant'Anna (2021)'s recommendation to summarize all feasible $ATT(g, t)$ into an overall effect parameter. Since we only have a limited number of bison herds established in each time period, the group size is small in our analysis. Statistical inference on group-time average treatment may become tenuous with small groups (Callaway and Sant'Anna 2021). Thus, we aggregate treatment effects of bison reintroduction on local economic outcomes by averaging all of the identified group-time average treatment effects with weights proportional to group size. In this case, the effective sample size is the total number of units that have ever been treated, and the statistical inference results can be more stable. The overall effects of bison reintroduction on income per capita, jobs, and population density across all groups that have ever had bison herds established are discussed in "Difference-in-difference (DID) with multiple time periods." To examine if the conditional parallel trend assumption is satisfied, we aggregate the group-time average treatment effects to an event study plot to show the average treatment effects at different lengths of exposure to the treatment. The parallel trend assumption holds if the average effects are not significantly different from zero in the pre-treatment periods (Callaway and Sant'Anna 2021).

SCM

The SCM uses a data-driven approach to construct a synthetic unit that closely matches each of the treated counties in pre-treatment periods. In contrast to the DID, the SCM allows for the effects of time-varying unobserved factors (Kreif et al. 2016). This synthetic unit is a weighted average of several untreated counties, where the weights are determined in the pre-treatment periods regarding how closely the control units match the treated

---

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

county. We use this synthetic unit as the counterfactual for the treated county in post-treatment periods to assess the effects of bison reintroduction on local economic development (Abadie and Gardeazabal 2003; Abadie et al. 2010; Abadie et al. 2015). As a small-sample comparative case study approach, this method also provides more informative results on how bison reintroduction affects each treated county's local economy and the effects on outcome variables during each post-treatment period.

We use the SCM to examine the treatment effects of bison reintroduction on local economic development. We estimate the county-specific effects of bison reintroduction and the average effects across each county with bison herds. In the following paragraphs, we first discuss how we follow Abadie et al. (2010, 2015) and conduct the SCM for each single treated county. Then, we explain how to generalize this SCM for multiple treated units following Cavallo et al. (2013).

For a single county with bison reintroduction, suppose we have $J + 1$ counties observed for T time periods, and only the first county has bison herds, while the remaining J counties are considered potential controls (donors). Suppose time periods 1 to T_0 are the pre-treatment periods and $T_0 + 1$ to T are the post-treatment periods, the bison reintroduction occurs at $T_0 + 1$. Let Y_{jt}^N be a vector of outcome variables that would be observed for county j at time t in the absence of treatment and Y_{jt}^J be the observed outcome if j is treated in the periods $T_0 + 1$ to T. Assuming bison reintroduction did not affect the bison county in the pre-treatment periods, we have $Y_{jt}^N = Y_{jt}^J$ for all j in 1, ... –N during t in 1, ...,T_0.

Let $\alpha_{jt} = Y_{jt}^J - Y_{jt}^N$ represents the effect of bison reintroduction for county j at time t. Given that only the first county is treated after $T_0 + 1$, we aim to estimate, α_{1t}, during the post-treatment periods ($t > T_0$). As shown in Equation 3, α_{1t} can be written as:

$$\alpha_{1t} = Y_{1t}^J - Y_{1t}^N \tag{3}$$

Given that Y_{1t}^J is observed, we find α_{1t} by estimating Y_{1t}^N with the SCM and replacing the unobserved Y_{1t}^N in Equation 3 with a synthetic counterfactual outcome. Y_{1t}^N can be estimated by applying a reduced-form model given by Abadie et al. (2010):

$$Y_{jt}^N = \sigma_t + \theta_t Z_j + \lambda_t \mu_j + \varepsilon_{jt} \tag{4}$$

where σ_t is the unknown time constant factor on Y_{jt}^N across counties; Z_j is a vector of observed covariates that are affected by bison reintroduction and used as the predictors of the outcome variables; μ_j is the unobserved determinants of Y with its effect λ_t allowing to vary over time; and the error terms ε_{jt} are unobserved factors with zero mean.

Y_{1t}^N is estimated by using a weighted average of the outcome Y_{jt}^N of the donors. Thus,

$$\hat{Y}_{1t}^N = \sum_{j=2}^{J+1} w_j Y_{jt} = \sigma_t + \theta_t \sum_{j=2}^{J+1} w_j Z_j + \lambda_t \sum_{j=2}^{J+1} w_j \mu_j + \sum_{j=2}^{J+1} w_j \varepsilon_{jt} \tag{5}$$

where $W = (w_2, \ldots, w_{J+1})$ is a vector of weights for the donors in the donor pool such that $w_j \geq 0$ for $j = 2, \ldots, J + 1$ and $w_2 + \ldots + w_{J+1} = 1$. Each particular value of the vector **W** defines a potential synthetic control.

Assume that there exists a set of weights $W^* = (w_2, \ldots, w_{J+1})$ such that

$$\sum_{j=2}^{J+1} w_j^* Y_{jt} = Y_{1t} \, for \, in \, (1, \ldots, T_0) \quad and \quad \sum_{j=2}^{J+1} w_j^* Z_{jt} = Z_1 \tag{6}$$

then as proved by Abadie et al. (2010), $\hat{Y}_{1t}^N$ will be an unbiased estimator of Y_{1t}^N and α_{1t} can be estimated using

$$\hat{\alpha}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} w_j Y_{jt} \tag{7}$$

Using $\mathbf{W}^\star$ produces a weighted average of the available control units such that it closely mimics the treated county in terms of outcomes during the pre-intervention periods. $\mathbf{W}^\star$ is chosen to minimize the difference between the characteristics of the treated and synthetic control counties (Abadie et al. 2010). The root means squared prediction error (RMSPE) in the pre-treatment periods can be used to measure the goodness of fit of a synthetic county (Abadie et al. 2015). A large RMSPE signals a bad fit, which may increase inference uncertainty in the post-treatment periods.

We select non-bison counties into a donor pool and construct a synthetic county for a treated unit as a weighted average of the units in the donor pool. Selecting donors before implementing SCM narrows the difference between the treated and donor units regarding the observed characteristics and reduces the potential interpolation bias. It also reduces the donor pool's size, saving computing time for the SCM estimation and avoiding overfitting (Abadie et al. 2010, 2015). We use propensity score nearest neighbor matching (one to thirty) to select non-bison counties as potential controls in the donor pool for wild and non-wild bison counties, respectively.[2, 3] Propensity scores are calculated using data on observed county geographical and socioeconomic characteristics – the same sets of covariates used in the DID approach.

Predictors used in the synthetic control estimation process include annual precipitation, annual temperature, and lagged outcome variables in pre-treatment periods. Both precipitation and temperature are averaged over the pre-treatment period when used as predictors. Kaul et al. (2015) point out that including all pre-treatment outcomes as separate predictors could bias the estimation. Therefore, only the lagged values of outcomes in the last five periods before the treatment year are included as separate predictors. The rest of the pre-treatment outcome lags are averaged when entering as a predictor.

We use a placebo test to determine the statistical significance of the estimated impacts of bison reintroduction (Abadie and Gardeazabal 2003; Abadie et al. 2010). For each treated county, we assign the same bison herd establishment year as a placebo to its donors in the donor pool and apply the SCM to every donor in our sample. Then, we examine if the estimated effect of a real bison reintroduction is large relative to the "treatment" effects produced by multiple placebo units in the donor pool. We can compute a lead-specific significance level (p-value) in the post-treatment period for the estimated impact as:

$$p - value = Pr(\hat{\alpha}_{1,l}^{PL} > \hat{\alpha}^{1,l}) = \frac{\sum_{j=2}^{J+1} I(\hat{\alpha}_{1,l}^{PL(j)} > \hat{\alpha}^{1,l})}{\# of \ control \ counties \ in \ the \ door \ pool} \tag{8}$$

where $\hat{\alpha}_{1,l}^{PL(j)}$ is the lead l-specific effect of bison reintroduction when a donor county j is assumed to have bison herd established at the same time as county 1. We use the p-value to assess how the estimate $\hat{\alpha}_{1,l}$ ranks in the distribution of placebo effects.

Given the lead-specific estimates for one treated county is $(\hat{\alpha}_{1,T_0+1}, \ldots, \hat{\alpha}_{1,T})$, we generalize the SCM to allow G counties to experience treatment at different times. The average effect over all the treatments is calculated as:

---

[2]The difference between wild and non-wild bison herds is discussed in Section 3.

[3]The matching is conducted with replacement. All wild bison counties share the same donor pool with 169 donors while all non-wild bison counties share the same donor pool with 224 donors

$$\bar{\alpha} = \frac{1}{G} \sum_{g=1}^{G} (\hat{\alpha}_{g,T_{0+1}} \ldots, \hat{\alpha}_{g,T}), \tag{9}$$

To conduct statistical inference for $\bar{\alpha}$, we construct a set of placebos $\bar{\alpha}^{PL}$ with which $\bar{\alpha}$ is compared for inference. We first compute all the placebo effects for each treated county, and then, we compute every possible placebo average effect at each lead. All the possible placebo averages are indexed by $np = 1, \ldots, N_{\tilde{P}L}$. Each placebo average is calculated by picking a single placebo estimate corresponding to each treated county g and then taking the average across all G placebos. We rank the actual lead-specific average treatment effect in the distribution of average placebo effects and compute the lead-specific p-value for the average effect of bison reintroduction. The p-value shows the proportion of average placebo effects that are at least as large as the average treatment effect.

$$p - value_l = \frac{\sum^{N\tilde{P}Lnp=1} I(\alpha_l^{P\tilde{L}(np)} > \bar{\alpha}_l)}{N_{\tilde{P}L}} \tag{10}$$

Data

This study uses three types of data constructed annually at the county level from 1969 to 2018: bison herd locations and characteristics, county-level economic measures, and physical characteristics of the land and climate. Table 1 shows the sources of variables used in the analysis. Data on outcome variables – per capita income, population, and the total number of jobs – come from the BEA. Data on county characteristics – temperature, precipitation, elevation, presence of grassland, and non-rural status – come from PRISM Climate Data, the National Map from U.S. Geological Survey[4], the National Land Cover Database (NLCD), and the BEA. The percentage of land within a county that is grassland or shrubs is calculated by overlaying a shapefile that contains counties' boundaries on raster data on national land cover from NLCD.

Information on bison herds is gathered from International Union for Conservation of Nature (IUCN), U.S. Department of the Interior National Park Service (DOI 2014), American Prairie Reserve Report (APR 2017), and Davenport (2018). Table A1 in the Appendix lists the establishment year and county locations of all the bison herds. Our data include fifty-three bison herds (including both wild and non-wild herds) established before 2018. Wild bison herds exist with limited or no human intervention; they range widely and serve authentic functions in their grassland habitats. In contrast, non-wild bison herds are fenced in and managed with veterinary care, providing value in display, research, and education. For example, the bison herd in Yellowstone is wild, while the Midewin National Tallgrass Prairie in Illinois hosts a display herd a short drive from Chicago.

Collectively, 66 counties in the U.S. have bison herds established. The maps in Figures 1, 2, and 3 visualize spatial patterns in the locations of those herds and local economic conditions by county. We use simple cross-sectional probit analysis to quantify those patterns and identify what types of counties are more likely to have restored

---

[4]The National Map is provided by U.S. Geological Survey's (USGS): https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map

Table 1. Variables and data source

Variable	Year	Source
Outcomes		
Per capita income	1969–2018	Bureau of Economic Analysis
Population	1969–2018	Bureau of Economic Analysis
Total number of jobs	1969–2018	Bureau of Economic Analysis
Unemployment rate	1990–2018	Bureau of Labor Statistics
Covariates		
Mean temperature	1970–2018	PRISM Climate Data
Precipitation	1970–2018	PRISM Climate Data
Metropolitan county	1970–2018	Bureau of Economic Analysis
Elevation		The National Map from U.S. Geological Survey
Grassland and shrubs	2001, 2004, 2006, 2008, 2011, 2013, 2016	National Land cover
Bison herd information	2018	IUCN, DOI (2014), APR (2017), Davenport (2018)

IUCN: International Union for Conservation of Nature; DOI: U.S. Department of the Interior National Park Service Report; APR: American Prairie Reserve Report.

bison herds (Table 2). The existence of non-wild bison herds is not significantly correlated with geographical or economic characteristics except elevation. The presence of wild herds is positively correlated with income and negatively correlated with population density if we only consider the socioeconomic variables. However, correlations between geography and socioeconomic characteristics mean those results disappear when geographic features are included. It seems wild bison herds are more likely to be established in cold areas with low precipitation and broad coverage by grasslands and shrubs.

Given that data for outcome variables are only available from the year 1969 to 2018, we can only conduct the DID analysis using a sub-sample of the treatment units. We select 30 counties with bison herds that were established between 1970 and 2018 as the treatment group.

Implementing SCM places more demands on the data for pre-and post-treatment information. Given that data on the outcomes and covariates data are available from 1969 to 2018, we select 14 bison herds established between the year 1980 and 2005 for the treatment sample in the SCM analyses. These 14 bison herds in 16 counties provide a representative mix of wild and non-wild bison herds in the Midwest and West regions.[5]

---

[5]These 14 bison herds are located in 16 counties because the Niobrara Valley Preserve is located in two counties in NE (Brown, NE and Keya Paha, NE), and the American Prairie Reserve is located in two counties in MT (Fergus, MT and Philips, MT)

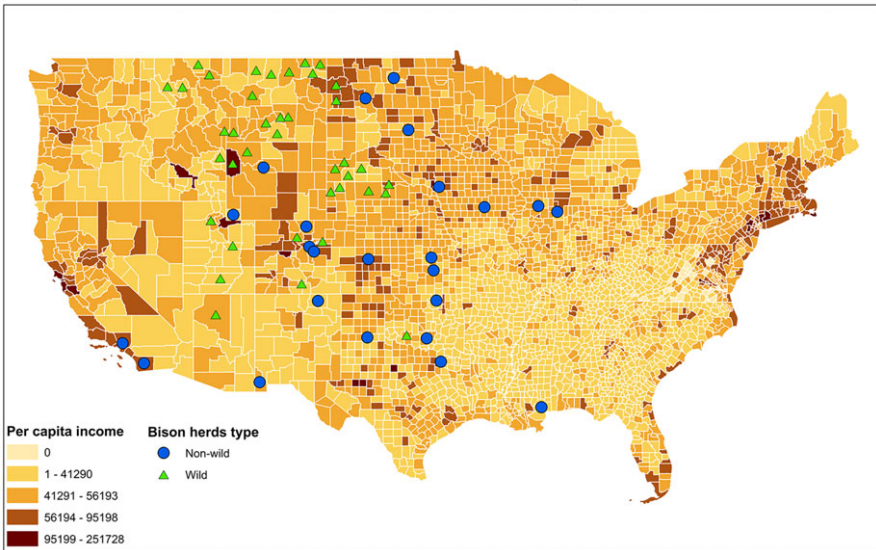## Bison Herds Distribution and Per Capita Income

Figure 1. Distribution of bison herds and income per capita in the U.S.

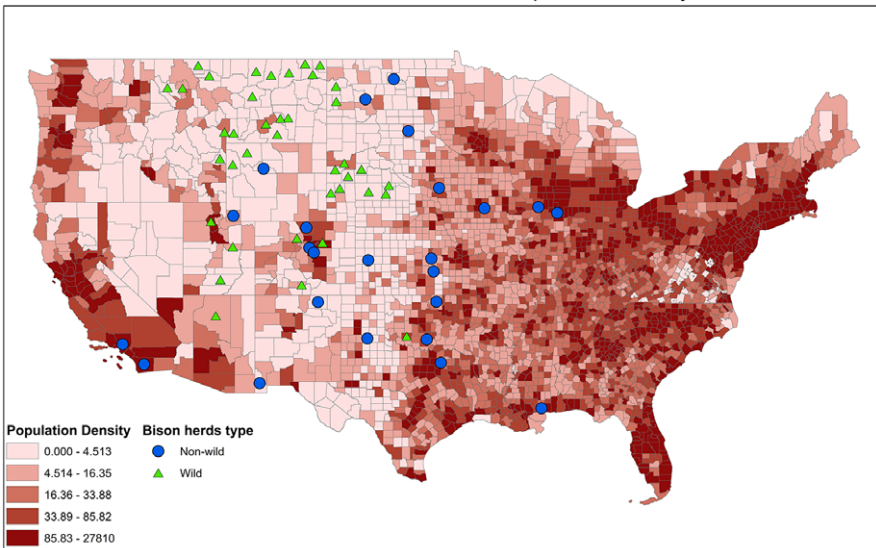## Bison Herds Distribution and Population Density

Figure 2. Distribution of bison herds and population density in the U.S.

Results

In this section, we report the estimated impacts of bison reintroduction on population density, per capita income, and total local employment using the DID and SCM approaches.
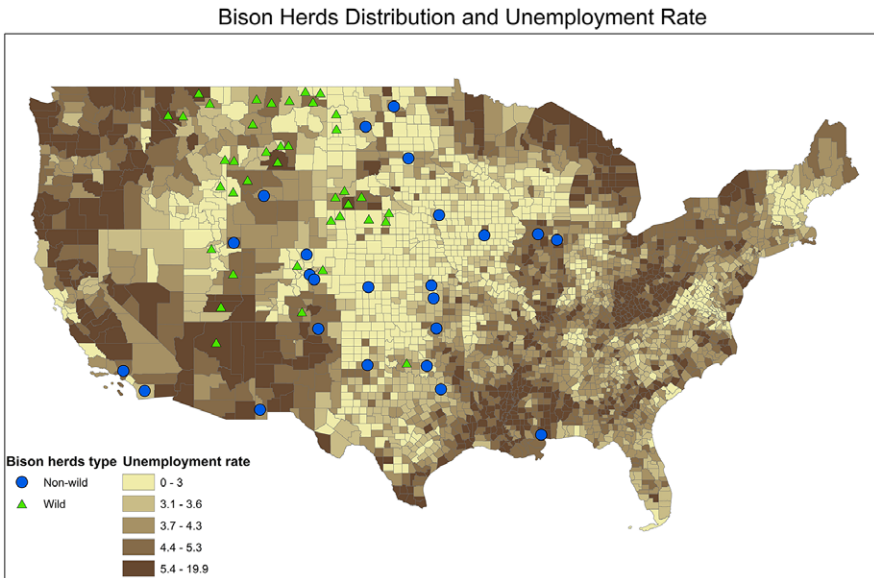
Bison Herds Distribution and Unemployment Rate

Figure 3. Distribution of bison herds and unemployment rate in the U.S.

DID with multiple time periods

Table 3 shows the effects of bison reintroduction on income per capita, population density, and the total number of jobs using the DID with DR estimation procedure. All outcomes are log-transformed, and standard errors are computed using the multiplier bootstrap. Point-estimate results imply that bison reintroduction reduces income per capita by 0.35%, population density by 2.41%, and the total number of jobs by 2.87%. However, all these effects on local economic development are insignificant. We also conduct the staggered DID using a pre-matched sample constructed by the propensity score matching (PSM). A detailed discussion of the DID with PSM results is available in Appendix B.

We graphically identify whether the conditional parallel trend assumption is satisfied using Figures 4, 5, and 6. These three figures present the average treatment effects of bison reintroduction at different lengths of exposure to treatment (similar to an event study plot) for the outcome variables income per capita, population density, and total number of jobs, respectively. Year zero represents the time period that a bison herd was established. The estimated coefficients show the average effects of bison reintroduction on a lag or lead before and after herds were established. The average effects are not significantly different from zero before herd establishments, implying that the conditional parallel trend assumption holds.

Figures 4–6 also help us explore the dynamic treatment effects of bison reintroduction. We focus on the dynamic effects within 20 years of post-treatment periods because we have fewer treated counties with bison herds established more than 20 years, resulting in large standard errors for the point estimates. We observe standard errors of the estimates increase significantly after 20 years of post-treatment periods, and thus, we should interpret the estimates with caution. The dynamic treatment effects of bison reintroduction are insignificant, but the point estimates hold interesting patterns. Figures 5 and 6 show a decreasing trend of population density and total number of jobs starting just a few years after reintroduction, while such trend does not exist when we focus on income

Table 2. Probit regression results

	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample	Full sample	Wild	Wild	Non-wild	Non-wild
Income per capita	0.0100***	0.00356	0.0112***	0.00474	0.00588	0.00278
	(0.00363)	(0.00384)	(0.00409)	(0.00446)	(0.00592)	(0.00636)
Unemployment rate	−0.00926	−0.0219	0.0243	0.0183	−0.108	−0.0986
	(0.0397)	(0.0435)	(0.0421)	(0.0509)	(0.0751)	(0.0766)
Population density	−0.000276	0.0000293	−0.00222***	0.0000390	0.00000915	0.0000336
	(0.000195)	(0.0000689)	(0.000849)	(0.000149)	(0.0000816)	(0.0000663)
Precipitation		−0.0215***		−0.0485***		−0.00820
		(0.00515)		(0.00989)		(0.00647)
Percentage of grassland and shrubs		0.724**		1.408***		0.0987
		(0.338)		(0.495)		(0.427)
Land area		0.0000466		0.0000396		0.0000144
		(0.0000298)		(0.0000332)		(0.0000518)
Avg mean temperature		−0.0334*		−0.103***		0.0163
		(0.0174)		(0.0278)		(0.0220)
Elevation		0.000165		−0.0000362		0.000312*
		(0.000116)		(0.000143)		(0.000165)
Constant	−2.418***	−1.469***	−2.676***	−0.731	−2.264***	−2.281***
	(0.268)	(0.393)	(0.301)	(0.523)	(0.462)	(0.602)
Observations	3039	3039	3015	3015	3000	3000

Standard errors in parentheses.
*$p < 0.10$.
**$p < 0.05$.
***$p < 0.01$.

Note: Table 2 summarizes the results of cross-sectional probit analyses. Results in Column (1) and (2) show whether a county has a bison herd in 2018 as a function of its characteristics. The dependent variable in Column (3) and (4) is a binary variable indicating if a county has a wild bison herd, while the dependent variable in Column (5) and (6) is a binary variable indicating if a county has non-wild bison herd.

per capita (Figure 4). This could be consistent with the fact that public bison herds require land for establishment but not much labor to maintain. We do note that in counties with bison herds established longer than 20 years, income, population, and employment all increase somewhat 20–30 years after reintroduction, albeit the effects are insignificant.

SCM results

The insignificant results of the DID with DR estimators methods could be associated with low power due to small numbers of treated counties. The SCM analyses take a different

Table 3. The effect of bison reintroduction: DID with doubly robust estimator

	(1) Income per capita	(2) Population density	(3) Total number of jobs
Bison	−0.0035	−0.0241	−0.0287
	(0.0385)	(0.0298)	(0.0317)
N	150100	150100	150100

Standard errors in parentheses.
Note: This table summarizes the effects of bison reintroduction on income per capita, the total number of jobs, and population density using DID with the doubly robust DID estimators. We include 30 counties with bison herds established between 1970 and 2018 in the treatment group to conduct the staggered DID analysis with multiple treatment periods.

Figure 4. Average effect on income per capita by years after herd establishment.
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 DR estimation procedure. Year 0 represents the time period that a bison herd was established. The average effects are not significantly different from 0 before herd establishment, implying that the parallel assumption is satisfied.

approach to exploring whether specific bison reintroductions had effects on their local economies.

We focus on six wild bison counties and ten non-wild bison counties with bison herds established between 1980 and 2005 as treated units in the SCM analyses. We first estimate the causal effects of bison reintroduction on per capita income, population, and the total number of jobs for each bison county and then calculate the average effects of bison reintroduction for counties with two different types of bison herds (wild vs non-wild)

Figure 5. Average effect on the total number of jobs by years after herd establishment.
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 DR estimation procedure. Year 0 represents the time period that a bison herd was established. The average effects are not significantly different from 0 before herd establishment, implying that the parallel assumption is satisfied.

respectively based on Equation 9.[6] To measure the statistical significance of the estimated average effects, we compute *p*-values using Equation (10).[7]

Table 4 summarizes the lead-specific average effects of bison reintroduction on local economic health for counties with wild and with non-wild bison herds.[8] We present the *p*-values for estimated effects in parentheses. The *p*-values are interpreted as the proportion of average placebo effects that are at least as large as the average treatment effect.[9] Exploring the point estimates of average effects over time, it appears the wild bison herds have positive impacts on income per capita (thousand dollars) in the first few post-treatment periods, but that effect then becomes negative. The non-wild bison herds

[6]We estimate the average effects of bison reintroduction for two different types of bison herds separately for two reasons. First, these two types of herds exist for different purposes and are managed differently, thus may potentially result in different local economic effects. Second, estimating the average effects for two separate groups reduce the computational demand for statistical inference calculation.

[7]To calculate the average effects of wild bison herds, we average the lead-specific effects across six counties with wild bison herds. To conduct statistical inference for wild bison herds, we consider the placebo effects corresponding to wild bison counties to construct a distribution of average placebo effects. Similar conduct is implemented for non-wild bison herds estimations.

[8]We also report the event-specific SCM results for each treated county in Appendix C using slightly different donor pools to construct synthetic units. Results suggest that bison reintroduction does not significantly impact per capita income, population, and local employment for both counties with wild and non-wild bison herds, which are consistent with the finding of the average effects of bison reintroduction.

[9]To get standardized measures, we divide all effects by the corresponding pre-treatment match quality (Cavallo et al., 2013)

Figure 6. Average effect on population density by years after herd establishment.
Note: This figure shows the average effects on population density across the different exposure lengths to the treatment. Results are estimated using DID with DR estimation procedure. Year 0 represents the time period that a bison herd was established. The average effects are not significantly different from 0 before herd establishment, implying that the parallel trend assumption is satisfied.

consistently have negative average impacts on per capita income. The estimated average effects of wild bison herds on population density and the total number of jobs are negative in all post-treatment periods, while the impacts of non-wild bison herds on population density and the total number of jobs are first positive and then become negative quickly. However, none of these estimates are statistically significant.

Conclusion

In this paper, we explore patterns in the locations of U.S. bison herd reintroduction and estimate the causal effects of those bison reintroduction on local economic health. We estimate the causal effects with two different econometric approaches: a staggered DID with multiple treatment periods and the SCM.

A simple probit analysis shows that wild bison herds are more likely to be established in counties with high income per capita; when geographic features are included, we see that wild bison herds are more commonly located in places with more grasslands, low precipitation, and low temperature. The naive correlation between income and bison herds might lead planners to think that bison reintroduction will increase per capita income in a county. However, none of the causal inference analyses find any statistically significant effects of bison reintroduction on per capita income, employment, or population density. These results are robust to different identifications and treatment samples we apply.

Why is there no effect of bison reintroduction on local economic activity? Many bison herds were established in pre-existing national monuments, state parks, or preserved areas.

Table 4. Average effects of bison reintroduction: synthetic control method

Leads	Income per capita		Population density		Total number of jobs	
	(1)	(2)	(3)	(4)	(5)	(6)
	Wild	Non-wild	Wild	Non-wild	Wild	Non-wild
1	0.005	−0.017	−0.012	0.012	−0.043	0.002
	(0.34)	(0.2)	(0.22)	(0.2)	(0.03)	(0.33)
2	0.002	−0.003	−0.022	0.015	−0.021	0.017
	(0.59)	(0.47)	(0.2)	(0.35)	(0.12)	(0.36)
3	0.003	−0.007	−0.032	0.008	−0.023	−0.002
	(0.64)	(0.27)	(0.16)	(0.69)	(0.37)	(0.79)
4	0.019	−0.017	−0.038	0.012	−0.04	−0.007
	(0.69)	(0.31)	(0.18)	(0.74)	(0.31)	(0.63)
5	−0.005	−0.001	−0.04	−0.002	−0.033	−0.021
	(0.9)	(0.89)	(0.25)	(0.92)	(0.47)	(0.74)
6	0.02	−0.016	−0.047	−0.004	−0.051	−0.01
	(0.56)	(0.51)	(0.25)	(0.87)	(0.31)	(0.86)
7	−0.068	0.021	−0.056	−0.021	−0.079	−0.011
	(0.47)	(0.6)	(0.26)	(0.68)	(0.2)	(0.93)
8	−0.097	0.015	−0.079	−0.028	−0.082	−0.033
	(0.13)	(0.94)	(0.16)	(0.64)	(0.24)	(0.81)
9	−0.097	0.003	−0.088	−0.038	−0.085	−0.06
	(0.14)	(0.81)	(0.16)	(0.58)	(0.29)	(0.54)
10	−0.153	−0.01	−0.081	−0.062	−0.07	−0.079
	(0.08)	(0.89)	(0.23)	(0.47)	(0.44)	(0.44)
11	−0.103	−0.005	−0.091	−0.074	−0.063	−0.103
	(0.14)	(0.77)	(0.26)	(0.46)	(0.49)	(0.24)
12	−0.046	−0.006	−0.084	−0.075	−0.044	−0.091
	(0.75)	(0.99)	(0.33)	(0.5)	(0.56)	(0.5)
13	−0.038	−0.019	−0.087	−0.082	−0.029	−0.113
	(0.59)	(0.97)	(0.37)	(0.51)	(0.66)	(0.32)
14	−0.004	−0.049	−0.094	−0.097	−0.047	−0.14
	(0.62)	(0.73)	(0.39)	(0.49)	(0.57)	(0.15)

Note: This table summarizes the lead-specific effects of bison reintroduction on income per capita, the total number of jobs, and population density in the post-treatment periods. We focus on six wild bison counties and ten non-wild bison counties with bison herds established between 1980 and 2005 as treated units in the SCM analyses. Column (1), (3), and (5) present the average effects of wild bison herd establishment on local economic health. Column (2), (4), and (6) present the average effects of non-wild bison herd establishment on local economic health. *p*-values are in parentheses.

Some research shows that the protection of public lands itself may have had minimal impact on the local economy (Jakus and Akhundjanov 2019); the addition of bison reintroduction may induce too little difference in land use to affect local economies.

The results of this paper may serve to assuage fears of farm, ranch, and local government leaders that bison reintroduction will harm local economies; no such pattern is supported by the evidence. On the other hand, we also do not find compelling evidence that bison herds increase local economic activity, as is sometimes anticipated by those who support reintroduction.

This paper has several important limitations. First, bison reintroduction may have other benefits that are not captured by the analyses in this paper. For example, bison may interact with dung beetles to improve the ecological functioning of grassland habitats and affect bird habitat and carbon sequestration (Barber et al. 2019). Furthermore, people may place large non-use values on the expanded existence of bison herds in the grasslands of the U.S. that could only be measured with a large-scale stated preference study. Future work would do well to quantify the non-market benefits of bison reintroduction and provide more information to guide ongoing efforts to restore this iconic mammal to the open lands of the U.S.

Second, this paper focuses on bison herds that have been restored and managed for conservation purposes on largely public or non-profit lands. The commercial bison industry has also expanded in the past few decades in the U.S. (Tielkes and Altmann 2021). Some commercial bison ranchers provide (agri)tourism opportunities in addition to meat production, which may mitigate the effects of reintroducing conservation bison herds in the same region. This paper should be interpreted as estimating the impacts of bison restoration for non-profit conservation purposes in a landscape where commercial bison herds have also been expanding. Future research could further explore the potential substitution effects between commercial and non-commercial herds in terms of (agri)tourism demand and amenity values.

References

Abadie, A. 2005. "Semiparametric Difference-in-Differences Estimators." *The Review of Economic Studies* **72**(1): 1–19.

Abadie, A., Diamond, A., and Hainmueller, J. 2010. "Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program." *Journal of the American Statistical Association* **105**(490): 493–505.

Abadie, A., Diamond, A., and Hainmueller, J. 2015. "Comparative Politics and the Synthetic Control Method." *American Journal of Political Science* **59**(2): 495–510.

Abadie, A., and Gardeazabal, J. 2003. "The Economic Costs of Conflict: A Case Study of the Basque Country." *American Economic Review* **93**(1): 113–132.

Albers, H., and Robinson, E. 2013. "A Review of the Spatial Economics of Non-Timber Forest Product Extraction: Implications for Policy." *Ecological Economics* **92**: 87–95.

Andam, K.S., Ferraro, P.J., Pfaff, A., Sanchez-Azofeifa, G.A., and Robalino, J.A. 2008. "Measuring the Effectiveness of Protected Area Networks in Reducing Deforestation." *Proceedings of the National Academy of Sciences* **105**(42): 16089–16094.

Andam, K.S., Ferraro, P.J., Sims, K.R., Healy, A., and Holland, M.B. 2010. "Protected Areas Reduced Poverty in Costa Rica and Thailand." *Proceedings of the National Academy of Sciences* **107**(22): 9996–10001.

APR. 2017. *Bison Report 2016–2017*. American Prairie Reserve. https://www.americanprairie.org/sites/default/files/APR_Bison%20Report_16_17.pdf

Barber, N.A., Hosler, S.C., Whiston, P., and Jones, H.P. 2019. "Initial Responses of Dung Beetle Communities to Bison Reintroduction in Restored and Remnant Tallgrass Prairie. *Natural Areas Journal* **39**(4): 420–428.

Bode, M., Tulloch, A.I., Mills, M., Venter, O., and Ando, W.A. 2015. "A Conservation Planning Approach to Mitigate the Impacts of Leakage from Protected Area Networks." *Conservation Biology* **29**(3): 765–774.

Borusyak, K., and Jaravel, X. 2017. *Revisiting Event Study Designs*. Available at SSRN 2826228.

Boyd, D.P., and Gates, C.C. 2006. "A Brief Review of the Status of Plains Bison in North America." *Journal of the West*, **45**(2): 15.

Callaway, B., and Sant'Anna, P.H. 2021. "Difference-in-Differences with Multiple Time Periods." *Journal of Econometrics* **225**(2): 200–230.

Cavallo, E., Galiani, S., Noy, I., and Pantano, J. 2013. "Catastrophic Natural Disasters and Economic Growth." *Review of Economics and Statistics* **95**(5): 1549–1561.

Chen, Y., Lewis, D.J., and Weber, B. 2016. "Conservation Land Amenities and Regional Economies: A Post-matching Difference-in-Differences Analysis of the Northwest Forest Plan. *Journal of Regional Science* **56**(3): 373–394.

Davenport, J. 2018. "Making the Buffalo Commons New Again: Rangeland Restoration and Bison Reintroduction in the Montana Highline." *Great Plains Quarterly* **38**(2): 199–225.

De Chaisemartin, C., and d'Haultfoeuille, X. 2020. "Two-Way Fixed Effects Estimators with Heterogeneous Treatment Effects." *American Economic Review* **110**(9): 2964–2996.

DOI. 2014. *Doi Bison Report: Looking Forward*. Natural Resource Report, National Park Service.

Duffield, J.W., Neher, C.J., and Patterson, D.A. 2008. "Wolf Recovery in Yellowstone: Park Visitor Attitudes, Expenditures, and Economic Impacts." In *The George Wright Forum*, **volume 25**, pp. 13–19. George Wright Society.

Eichman, H., Hunt, G.L., Kerkvliet, J., and Plantinga, A.J. 2010. "Local Employment Growth, Migration, and Public Land Policy: Evidence from the Northwest Forest Plan." *Journal of Agricultural and Resource Economics* **35**(2): 316–333.

Emerton, L. 2001. "The Nature of Benefits & the Benefits of Nature: Why Wildlife Conservation Has Not Economically Benefited Communities in Africa." In *African Wildlife and Livelihoods: The Promise and Performance of Community Conservation* (eds. D. Hulme and M. Murphree), pp. 208–226. London: James Currey.

Emmet Jones, R., Mark Fly, J., Talley, J., and Ken Cordell, H. 2003. "Green Migration into Rural America: The New Frontier of Environmentalism?" *Society &Natural Resources* **16**(3): 221–238.

Fernandez, A., Richardson, R.B., Tschirley, D.L., and Tembo, G. 2009. Wildlife Conservation in Zambia: Impacts on Rural Household Welfare. Technical Report.

Ferris, A.E., and Frank, E.G. 2021. "Labor Market Impacts of Land Protection: The Northern Spotted Owl." *Journal of Environmental Economics and Management* **109**: 102480.

Foelske, L., Van Riper, C.J., Stewart, W., Ando, A., Gobster, P., and Hunt, L. 2019. "Assessing Preferences for Growth on the Rural-Urban Fringe using a Stated Choice Analysis." *Landscape and Urban Planning* **189**: 396–407.

Goodman-Bacon, A. 2021. "Difference-in-Differences with Variation in Treatment Timing." *Journal of Econometrics* **225**(2): 254–277.

Heckman, J.J., Ichimura, H., and Todd, P.E. 1997. "Matching as an Econometric Evaluation Estimator: Evidence from Evaluating a Job Training Programme." *The Review of Economic Studies* **64**(4): 605–654.

Jakus, P.M. and Akhundjanov, S.B. 2019. "The Antiquities Act, National Monuments, and the Regional Economy." *Journal of Environmental Economics and Management*, **95**: 102–117.

Kaul, A., Klößner, S., Pfeifer, G., and Schieler, M. 2015. Synthetic Control Methods: Never Use All Pre-Intervention Outcomes as Economic Predictors." Unpublished. Available at: http://www.oekonometrie. uni-saarland.de/papers/SCMPredictors.pdf.

Kennedy, C.M., Miteva, D.A., Baumgarten, L., Hawthorne, P.L., Sochi, K., Polasky, S., Oakleaf, J.R., Uhlhorn, E.M., and Kiesecker, J. 2016. "Bigger Is Better: Improved Nature Conservation and Economic Returns from Landscape-Level Mitigation." *Science Advances* **2**(7): e1501021.

Kohl, M.T., Krausman, P.R., Kunkel, K., and Williams, D.M. 2013. "Bison versus Cattle: Are They Ecologically Synonymous?" *Rangeland Ecology & Management* **66**(6): 721–731.

Kreif, N., Grieve, R., Hangartner, D., Turner, A.J., Nikolova, S., and Sutton, M. 2016. "Examination of the Synthetic Control Method for Evaluating Health Policies with Multiple Treated Units." *Health Economics* **25**(12): 1514–1528.

Langpap, C., Kerkvliet, J., and Shogren, J.F. 2020. "The Economics of the US Endangered Species Act: A Review of Recent Developments." *Review of Environmental Economics and Policy* **12**(1): 69–91.

Lewis, D., Kaweche, G.B., and Mwenya, A. 1990. "Wildlife Conservation Outside Protected Areas—Lessons from an Experiment in Zambia." *Conservation Biology*, **4**(2): 171–180.

Lewis, D.J., Hunt, G.L., and Plantinga, A.J. 2002. "Public Conservation Land and Employment Growth in the Northern Forest Region." *Land Economics* **78**(2): 245–259.

Loomis, J. and Caughlan, L. 2004. "Linking Intended Visitation to Regional Economic Impact Models of Bison and Elk Management." *Human Dimensions of Wildlife* **9**(1): 17–33.

Rasker, R. 1993. "Rural Development, Conservation, and Public Policy in the Greater Yellowstone Ecosystem." *Society & Natural Resources* **6**(2): 109–126.

Raynor, J.L., Grainger, C.A., and Parker, D.P. 2021. "Wolves Make Roadways Safer, Generating Large Economic Returns to Predator Conservation." *Proceedings of the National Academy of Sciences* **118**(22): e2023251118.

Rosenbaum, P.R., and Rubin, D.B. 1985. "Constructing a Control Group using Multivariate Matched Sampling Methods that Incorporate the Propensity Score." *The American Statistician* **39**(1): 33–38.

Sant'Anna, P.H., and Zhao, J. 2020. "Doubly Robust Difference-in-Differences Estimators." *Journal of Econometrics* **219**(1): 101–122.

Taylor, M.S. 2011. "Buffalo Hunt: International Trade and the Virtual Extinction of the North American Bison." *American Economic Review* **101**(7): 3162–3195.

Tielkes, S., and Altmann, B.A. 2021. "The Sustainability of Bson Production in North America: A Scoping Review." *Sustainability* **13**(24): 13527.

Vasile, M. 2018. "The Vulnerable Bison: Practices and Meanings of Rewilding in the Romanian Carpathians." *Conservation and Society* **16**(3): 217–231.

Walls, M., Lee, P., and Ashenfarb, M. 2020. "National Monuments and Economic Growth in the American West." *Science Advances* **6**(12): eaay8523.

Wilkins, K., Pejchar, L., and Garvoille, R. 2019. "Ecological and Social Consequences of Bison Reintroduction in Colorado." *Conservation Science and Practice* **1**(2): e9.

Wilson, C., and Tisdell, C. 2003. "Conservation and Economic Benefits of Wildlife-Based Marine Tourism: Sea Turtles and Whales as Case Studies." *Human Dimensions of Wildlife* **8**(1): 49–58.

Winter, P.L., Selin, S., Cerveny, L., and Bricker, K. 2020. "Outdoor Recreation, Nature-Based Tourism, and Sustainability." *Sustainability* **12**(1): 81.

Wunder, S. 2000. "Ecotourism and Economic Incentives—An Empirical Approach." *Ecological Economics* **32**(3): 465–479.

Zumbach, L. 2015. "Bison Herd Returning to Prairie Scene." *Chicago Tribune*, **29**(Section 1): 9.