Tutorial on propensity score matching and inverse probability of treatment weighting

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Description

This tutorial demonstrates how to use propensity score matching and inverse probability of treatment weighting using a real dataset from Siegel et al. 2022. The dataset for the entire western US is very large and unwieldy, so you'll work with a subset of data for a single year in Colorado.

Set up

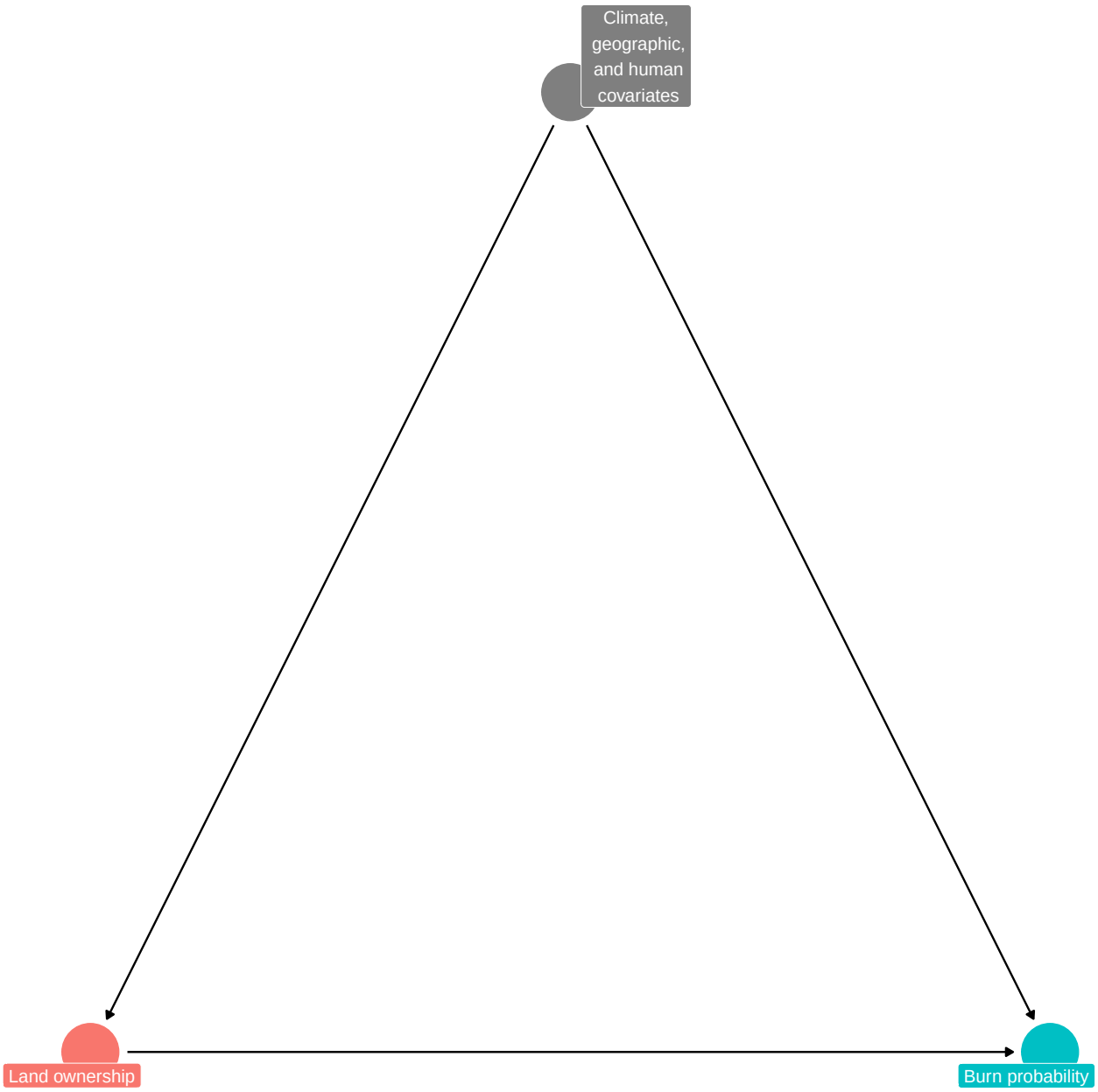
Load the packages used for data manipulation (tidyverse, sf), making a directed acyclic graph (ggdag), matching (MatchIt), weighting (ipw), and regression models (lme4).

The context

The Siegel et al. 2022 study examines the effect of forest management (through the proxy of land ownership) on annual burn probability in forests of the western US. Specifically, it looks at the effect of federal (treatment) vs. private (control) ownership on wildfire occurrence in sample units.

Directed acyclic graph

Here's a DAG for the research question:



The data

The data are in the file *matching_ipw_data_full.csv*.

Variable names

- state: the state the sample unit is from (Colorado)
- UID: a unique identifier for each sample unit
- year: the year that the fire and climate data is from (2002)
- burned: whether or not the unit burned in 2002 (0 = unburned, 1 = burned)

- prot_cat_recl: the ownership class. 0 = private, 1 = federal
- dist_rds_km: distance to the nearest road, in kiometers
- slope: slope, in degrees
- aspect_srai: solar radiation aspect index
- elev_km: elevation, in 1000 m
- lon: longitude
- lat: latitude
- pdsi_avg_season: seasonal average Palmer Drought Severity Index value (fall, spring, summer, winter)
- soil_avg_season: seasonal average soil moisture (fall, spring, summer, winter)
- tmmn_avg_season: seasonal average minimum temperature (fall, spring, summer, winter)
- tmmx_avg_season: seasonal average maximum temperature (fall, spring, summer, winter)
- vs_max_season: seasonal average maximum wind speed (fall, spring, summer, winter)
- total_precip_season: total seasonal precipitation (fall, spring, summer, winter)
- prev_yr_precip: total precipitation in the previous year

Data exploration

What's the breakdown of private (value = 0) vs. federal (value = 1) units?

Table 1: Units on federal (=1) and private (=0) land

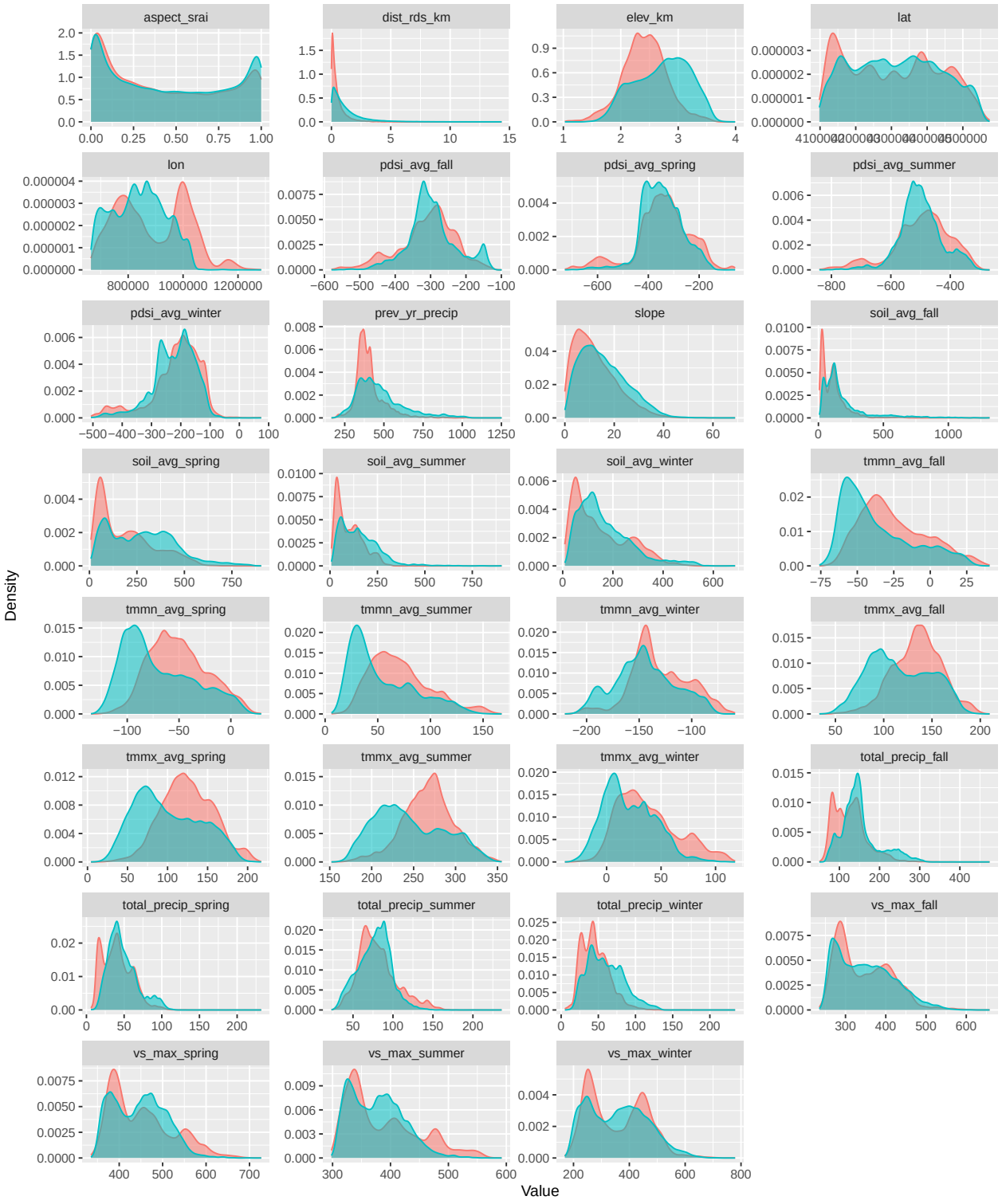
Var1	Freq
0	22877
1	60654

What's the breakdown of units that burned (value = 1) in 2002 vs. units that did not burn (value = 0)?

Table 2: Units that burned (=1) or did not burn (=0) in 2002

Var1	Freq
0	82189
1	1342

How do the private (in red) vs federal (in blue) units differ in terms of potential confounders?



Run naive regression

We could just run a naive regression, ignoring the potential impact of confounders. There are some highly correlated covariates in the model, but let's ignore them for now. Let's see what that would yield:

Table 3: Coefficient estimates for naive model

Variable	Estimate	Std. Error	p value
(Intercept)	-14.088	3.606	0.000
prot_cat_recl1	1.229	0.095	0.000
dist_rds_km	-0.079	0.029	0.007
slope	0.019	0.003	0.000
aspect_srai	0.149	0.084	0.077
elev_km	1.627	0.215	0.000
pdsi_avg_winter	-0.014	0.002	0.000
pdsi_avg_spring	-0.021	0.003	0.000
pdsi_avg_summer	0.036	0.004	0.000
pdsi_avg_fall	-0.004	0.003	0.143
soil_avg_winter	0.000	0.001	0.597
soil_avg_spring	0.006	0.001	0.000
soil_avg_summer	-0.002	0.001	0.200
soil_avg_fall	-0.002	0.001	0.003
tmmn_avg_winter	-0.112	0.011	0.000
tmmn_avg_spring	0.054	0.026	0.035
tmmn_avg_summer	-0.095	0.022	0.000
tmmn_avg_fall	0.131	0.026	0.000
tmmx_avg_winter	0.133	0.012	0.000
tmmx_avg_spring	-0.017	0.021	0.431
tmmx_avg_summer	0.265	0.021	0.000
tmmx_avg_fall	-0.395	0.029	0.000
vs_max_winter	0.044	0.004	0.000
vs_max_spring	-0.038	0.005	0.000
vs_max_summer	-0.007	0.005	0.157
vs_max_fall	-0.045	0.006	0.000
total_precip_winter	-0.152	0.008	0.000
total_precip_spring	-0.034	0.007	0.000
total_precip_summer	0.130	0.007	0.000
total_precip_fall	0.044	0.005	0.000
prev_yr_precip	-0.003	0.003	0.196

Use matching to overcome issues with observed confounding variables

Match the data

Match the data on the observable covariates, using the MatchIt package. You can play around with the settings to see how it affects the matched data you end up with.

Assess match quality Take a look at the quality of the matches: how many units were matched? Control = private units, Treated = federal units

Table 4: Breakdown of matched and unmatched units

	Control	Treated
All (ESS)	22877	60654
All	22877	60654
Matched (ESS)	14938	14938
Matched	14938	14938
Unmatched	7939	45716

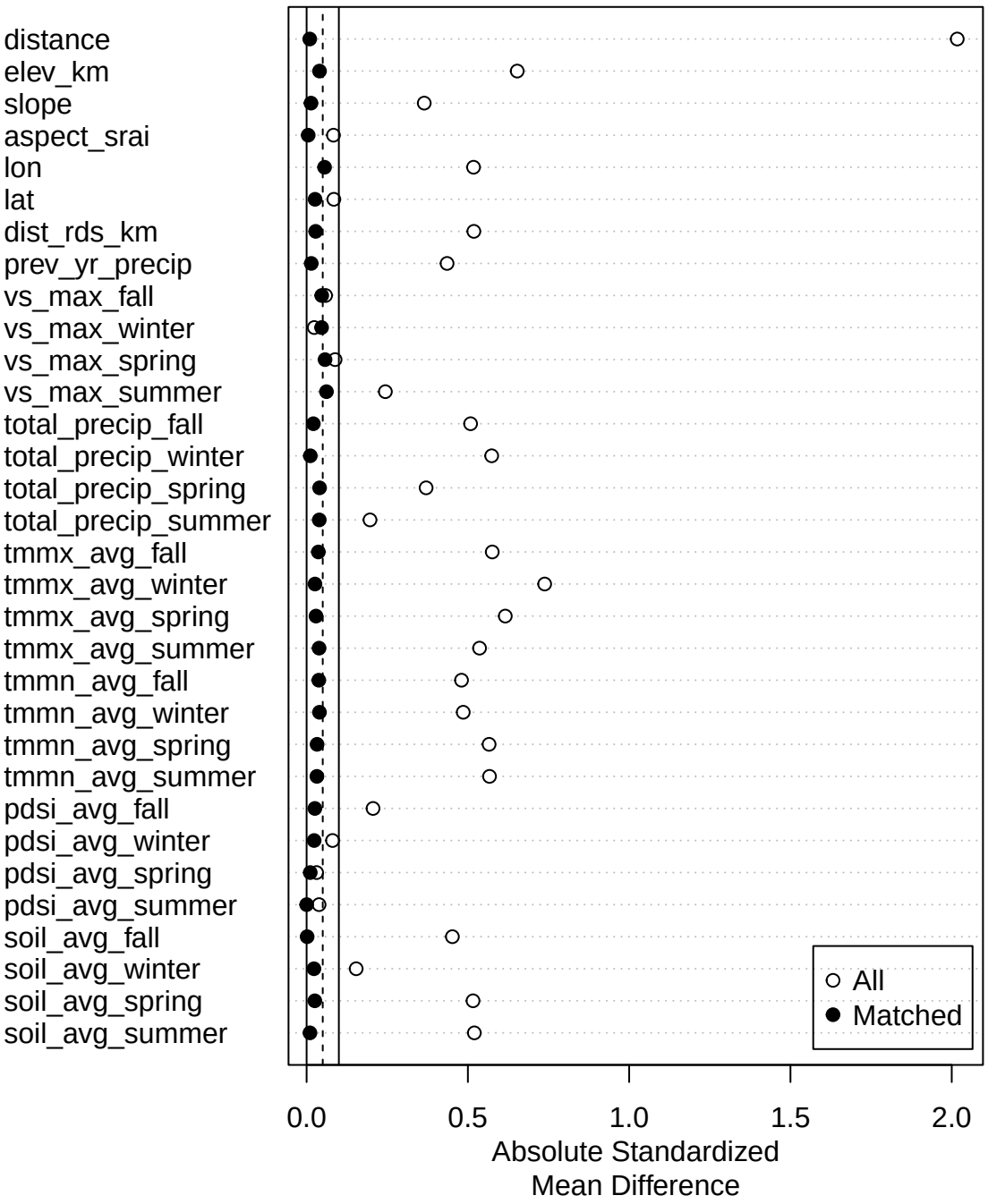
	Control	Treated
Discarded	0	0

What are the covariate means in the matched dataset for the treated (federal) and control (private) units? What was the covariate balance after matching?

Table 5: Covariate balance of matched dataset

	Means Treated	Means Control	Standardized Mean Difference
distance	0.6176753	0.6159249	0.0097356
elev_km	2.5050548	2.4863461	0.0400567
slope	13.2895054	13.1615933	0.0136513
aspect_srai	0.4434631	0.4417718	0.0048726
lon	850426.2190646	845125.3755782	0.0556395
lat	4318802.1473203	4321945.7408402	-0.0261716
dist_rds_km	0.5675395	0.5293742	0.0280990
prev_yr_precip	415.9040702	413.7277413	0.0144695
vs_max_fall	333.4836658	330.2121435	0.0468708
vs_max_winter	337.5288526	332.6482126	0.0464294
vs_max_spring	433.5542911	430.1847637	0.0571572
vs_max_summer	369.9467131	367.1889142	0.0615369
total_precip_fall	135.7182354	136.7065872	-0.0208935
total_precip_winter	49.2533806	48.9771723	0.0114902
total_precip_spring	43.4141117	44.2030392	-0.0402520
total_precip_summer	74.1821529	73.3912840	0.0393248
tmmx_avg_fall	129.5242112	130.6990673	-0.0365026
tmmx_avg_winter	30.8287366	31.4374526	-0.0260074
tmmx_avg_spring	117.5735931	118.7585353	-0.0291529
tmmx_avg_summer	262.1871067	263.7826795	-0.0387457
tmmn_avg_fall	-29.5185656	-28.6019994	-0.0378251
tmmn_avg_winter	-136.7468871	-135.5923372	-0.0399056
tmmn_avg_spring	-56.6414960	-55.5360602	-0.0324382
tmmn_avg_summer	64.6299817	65.6129335	-0.0318858
pdsi_avg_fall	-307.9482528	-306.1752800	-0.0256482
pdsi_avg_winter	-221.6212344	-223.2983220	0.0233756
pdsi_avg_spring	-351.6000580	-352.4973223	0.0113455
pdsi_avg_summer	-504.7072790	-504.7183916	0.0001548
soil_avg_fall	124.6150533	124.9170349	-0.0016596
soil_avg_winter	163.1105012	165.5299683	-0.0227459
soil_avg_spring	210.8377962	215.2270496	-0.0254500
soil_avg_summer	113.2771902	114.3229125	-0.0104162

Comparison of standardized mean differences in the covariate values in the full vs. matched dataset



Analyze the matched dataset

Extract the matched data First, you'll need to extract the matched data and use the UIDs from the matched data to subset the full dataset for analysis.

Model the effect of ownership/management on wildfire probability Again, there are correlated covariates, but let's just ignore them

Table 6: Coefficient estimates for model with matching

Variable	Estimate	Std. Error	p value
(Intercept)	-34.128	7.665	0.000
prot_cat_recl1	1.013	0.115	0.000
dist_rds_km	-0.110	0.106	0.299
slope	0.026	0.006	0.000
aspect_srai	0.059	0.139	0.670
elev_km	1.801	0.407	0.000
pdsi_avg_winter	-0.020	0.004	0.000
pdsi_avg_spring	-0.019	0.006	0.002
pdsi_avg_summer	0.027	0.009	0.002
pdsi_avg_fall	-0.002	0.006	0.765
soil_avg_winter	0.001	0.002	0.505
soil_avg_spring	0.009	0.002	0.000
soil_avg_summer	-0.005	0.003	0.097
soil_avg_fall	-0.001	0.001	0.388
tmmn_avg_winter	-0.075	0.020	0.000
tmmn_avg_spring	-0.086	0.044	0.049
tmmn_avg_summer	-0.122	0.042	0.004
tmmn_avg_fall	0.220	0.049	0.000
tmmx_avg_winter	0.168	0.023	0.000
tmmx_avg_spring	-0.039	0.038	0.306
tmmx_avg_summer	0.485	0.042	0.000
tmmx_avg_fall	-0.597	0.057	0.000
vs_max_winter	0.046	0.008	0.000
vs_max_spring	-0.089	0.013	0.000
vs_max_summer	0.004	0.010	0.713
vs_max_fall	-0.030	0.013	0.025
total_precip_winter	-0.272	0.018	0.000
total_precip_spring	-0.136	0.015	0.000
total_precip_summer	0.007	0.016	0.664
total_precip_fall	-0.003	0.010	0.773
prev_yr_precip	0.056	0.007	0.000

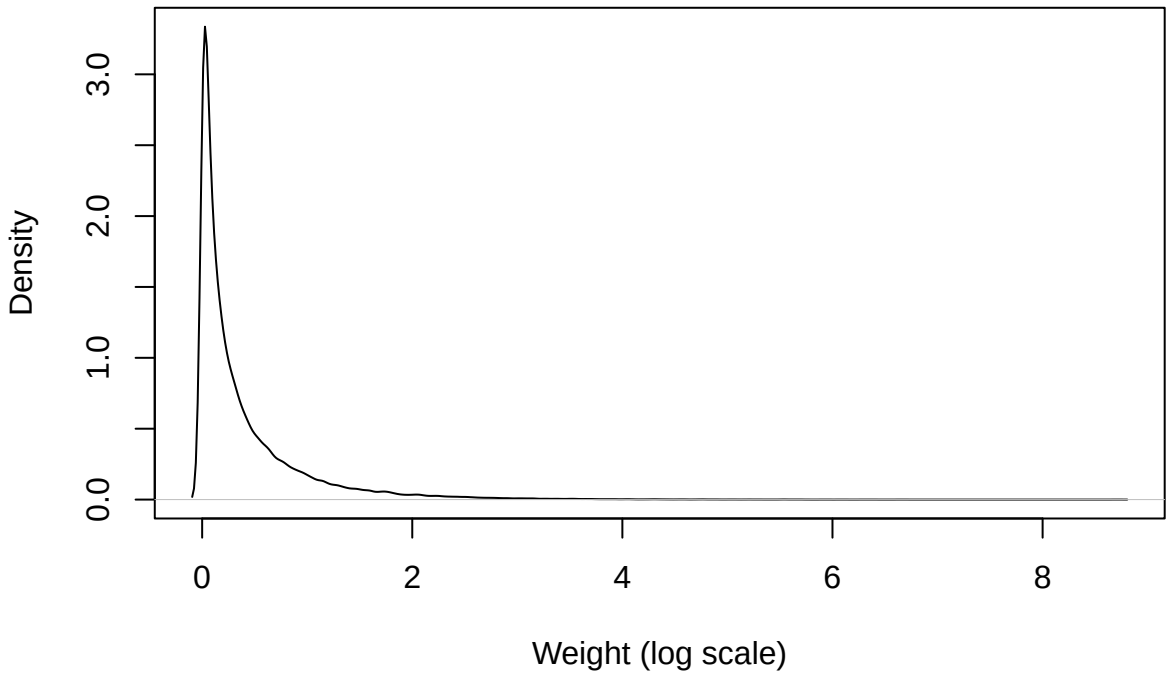
Use weighting to overcome issues with observed confounding variables

Weight the data

Use the package ipw

What's the range of weights?

```
## [1]    1.00 6069.64
```



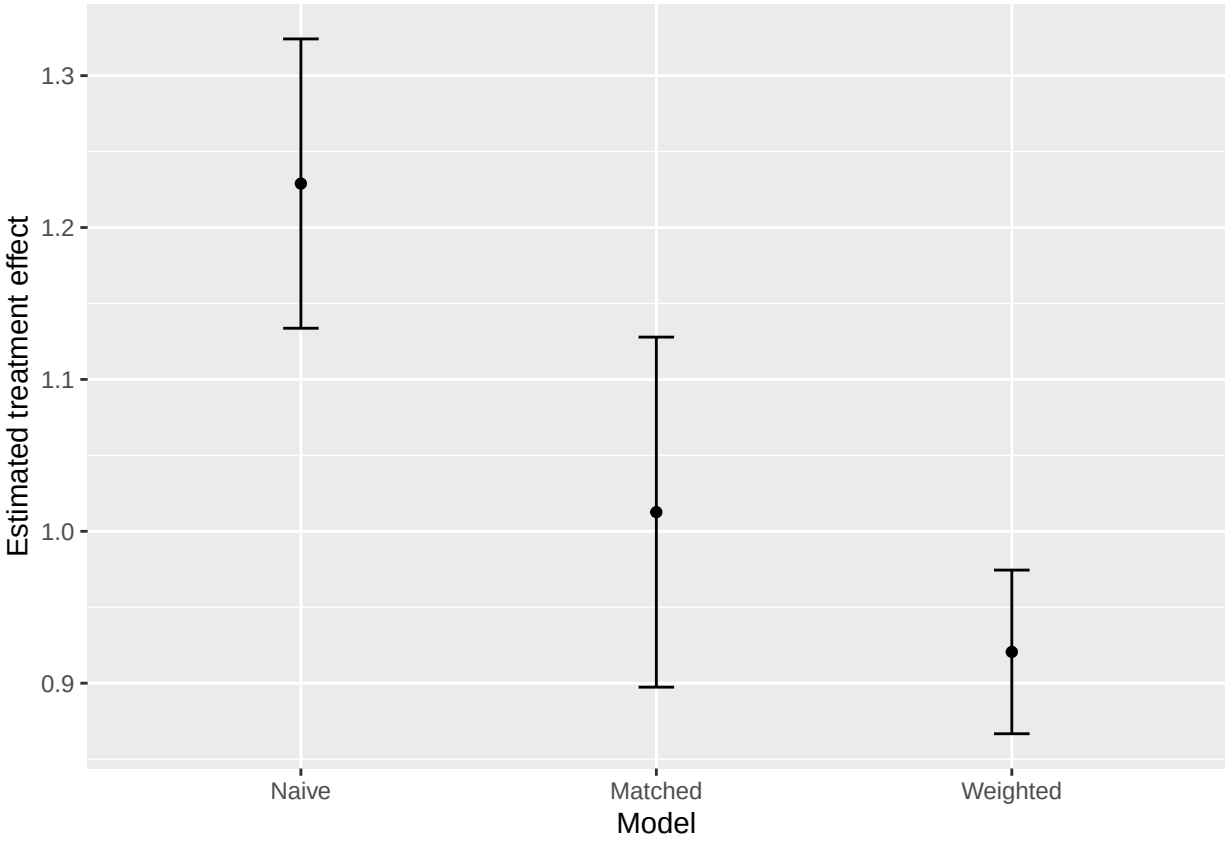
Model the effect of ownership

Table 7: Coefficient estimates for model with weighting

Variable	Estimate	Std. Error	p value
(Intercept)	-11.151	2.821	0.000
prot_cat_recl1	0.921	0.054	0.000
dist_rds_km	-0.014	0.026	0.581
slope	0.011	0.003	0.000
aspect_srai	0.077	0.066	0.245
elev_km	1.890	0.174	0.000
pdsi_avg_winter	-0.018	0.002	0.000
pdsi_avg_spring	-0.020	0.002	0.000
pdsi_avg_summer	0.036	0.003	0.000
pdsi_avg_fall	-0.003	0.002	0.130
soil_avg_winter	-0.001	0.001	0.331
soil_avg_spring	0.008	0.001	0.000
soil_avg_summer	-0.003	0.001	0.005
soil_avg_fall	-0.002	0.001	0.000
tmmn_avg_winter	-0.118	0.008	0.000
tmmn_avg_spring	0.059	0.019	0.002
tmmn_avg_summer	-0.127	0.017	0.000
tmmn_avg_fall	0.158	0.021	0.000
tmmx_avg_winter	0.152	0.009	0.000
tmmx_avg_spring	-0.026	0.016	0.108
tmmx_avg_summer	0.299	0.016	0.000
tmmx_avg_fall	-0.431	0.023	0.000
vs_max_winter	0.054	0.003	0.000
vs_max_spring	-0.060	0.004	0.000
vs_max_summer	0.001	0.004	0.863
vs_max_fall	-0.042	0.005	0.000

Variable	Estimate	Std. Error	p value
total_precip_winter	-0.165	0.006	0.000
total_precip_spring	-0.061	0.005	0.000
total_precip_summer	0.089	0.006	0.000
total_precip_fall	0.039	0.004	0.000
prev_yr_precip	0.004	0.002	0.060

Compare outputs from the naive, matched, and weighted regressions




```
## List of 136
##  $ line                            :List of 6
##   ..$ colour       : chr "black"
##   ..$ linewidth    : num 0.5
##   ..$ linetype     : num 1
##   ..$ lineend      : chr "butt"
##   ..$ arrow        : logi FALSE
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_line" "element"
##  $ rect                            :List of 5
##   ..$ fill         : chr "white"
##   ..$ colour       : chr "black"
##   ..$ linewidth    : num 0.5
##   ..$ linetype     : num 1
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_rect" "element"
##  $ text                            :List of 11
```

```
##   ..$ family       : chr ""
##   ..$ face         : chr "plain"
##   ..$ colour       : chr "black"
##   ..$ size         : num 11
##   ..$ hjust        : num 0.5
##   ..$ vjust        : num 0.5
##   ..$ angle        : num 0
##   ..$ lineheight   : num 0.9
##   ..$ margin       : 'margin' num [1:4] 0points 0points 0points 0points
##   .. ..- attr(*, "unit")= int 8
##   ..$ debug        : logi FALSE
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ title                          : NULL
##  $ aspect.ratio                   : NULL
##  $ axis.title                     : NULL
##  $ axis.title.x                   :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : NULL
##   ..$ hjust        : NULL
##   ..$ vjust        : num 1
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : 'margin' num [1:4] 2.75points 0points 0points 0points
##   .. ..- attr(*, "unit")= int 8
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ axis.title.x.top               :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : NULL
##   ..$ hjust        : NULL
##   ..$ vjust        : num 0
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : 'margin' num [1:4] 0points 0points 2.75points 0points
##   .. ..- attr(*, "unit")= int 8
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ axis.title.x.bottom            : NULL
##  $ axis.title.y                   :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : NULL
##   ..$ hjust        : NULL
##   ..$ vjust        : num 1
##   ..$ angle        : num 90
##   ..$ lineheight   : NULL
```

```
##   ..$ margin       : 'margin' num [1:4] 0points 2.75points 0points 0points
##   .. ..- attr(*, "unit")= int 8
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ axis.title.y.left               : NULL
##  $ axis.title.y.right              :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : NULL
##   ..$ hjust        : NULL
##   ..$ vjust        : num 1
##   ..$ angle        : num -90
##   ..$ lineheight   : NULL
##   ..$ margin       : 'margin' num [1:4] 0points 0points 0points 2.75points
##   .. ..- attr(*, "unit")= int 8
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##   ..$ inherit.blank: logi TRUE
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##  $ axis.text                       :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : chr "grey30"
##   ..$ size         : 'rel' num 0.8
##   ..$ hjust        : NULL
##   ..$ vjust        : NULL
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : NULL
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi TRUE
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##  $ axis.text.x                     :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : NULL
##   ..$ hjust        : NULL
##   ..$ vjust        : num 1
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : 'margin' num [1:4] 2.2points 0points 0points 0points
##   .. ..- attr(*, "unit")= int 8
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ axis.text.x.top                 :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : NULL
##   ..$ hjust        : NULL
##   ..$ vjust        : num 0
```

```
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : 'margin' num [1:4] 0points 0points 2.2points 0points
##   .. ..- attr(*, "unit")= int 8
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ axis.text.x.bottom              : NULL
##  $ axis.text.y                     :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : NULL
##   ..$ hjust        : num 1
##   ..$ vjust        : NULL
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : 'margin' num [1:4] 0points 2.2points 0points 0points
##   .. ..- attr(*, "unit")= int 8
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ axis.text.y.left                : NULL
##  $ axis.text.y.right               :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : NULL
##   ..$ hjust        : num 0
##   ..$ vjust        : NULL
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : 'margin' num [1:4] 0points 0points 0points 2.2points
##   .. ..- attr(*, "unit")= int 8
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##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ axis.text.theta                 : NULL
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##   ..$ vjust        : NULL
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
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##   .. ..- attr(*, "unit")= int 8
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ axis.ticks                      :List of 6
##   ..$ colour       : chr "grey20"
```

```
##   ..$ linewidth    : NULL
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##   ..$ lineend      : NULL
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##   ..$ inherit.blank: logi TRUE
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##  $ axis.ticks.x.top               : NULL
##  $ axis.ticks.x.bottom            : NULL
##  $ axis.ticks.y                   : NULL
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##  $ axis.ticks.y.right             : NULL
##  $ axis.ticks.theta               : NULL
##  $ axis.ticks.r                   : NULL
##  $ axis.minor.ticks.x.top         : NULL
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##  $ axis.minor.ticks.y.left        : NULL
##  $ axis.minor.ticks.y.right       : NULL
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##  $ axis.minor.ticks.r             : NULL
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##  $ axis.ticks.length.x.bottom     : NULL
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##  $ axis.ticks.length.y.left       : NULL
##  $ axis.ticks.length.y.right      : NULL
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##  $ axis.ticks.length.r            : NULL
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##  $ axis.minor.ticks.length.x.bottom: NULL
##  $ axis.minor.ticks.length.y      : NULL
##  $ axis.minor.ticks.length.y.left : NULL
##  $ axis.minor.ticks.length.y.right : NULL
##  $ axis.minor.ticks.length.theta  : NULL
##  $ axis.minor.ticks.length.r      : NULL
##  $ axis.line                      : list()
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##  $ axis.line.x.bottom             : NULL
##  $ axis.line.y                    : NULL
##  $ axis.line.y.left               : NULL
##  $ axis.line.y.right              : NULL
##  $ axis.line.theta                : NULL
##  $ axis.line.r                    : NULL
##  $ legend.background              :List of 5
##   ..$ fill         : NULL
##   ..$ colour       : logi NA
##   ..$ linewidth    : NULL
##   ..$ linetype     : NULL
```

```
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_rect" "element"
##  $ legend.margin                   : 'margin' num [1:4] 5.5points 5.5points 5.5points 5.5points
##   ..- attr(*, "unit")= int 8
##  $ legend.spacing                  : 'simpleUnit' num 11points
##   ..- attr(*, "unit")= int 8
##  $ legend.spacing.x                : NULL
##  $ legend.spacing.y                : NULL
##  $ legend.key                      : NULL
##  $ legend.key.size                 : 'simpleUnit' num 1.2lines
##   ..- attr(*, "unit")= int 3
##  $ legend.key.height               : NULL
##  $ legend.key.width                : NULL
##  $ legend.key.spacing              : 'simpleUnit' num 5.5points
##   ..- attr(*, "unit")= int 8
##  $ legend.key.spacing.x            : NULL
##  $ legend.key.spacing.y            : NULL
##  $ legend.frame                    : NULL
##  $ legend.ticks                    : NULL
##  $ legend.ticks.length             : 'rel' num 0.2
##  $ legend.axis.line                : NULL
##  $ legend.text                     :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : 'rel' num 0.8
##   ..$ hjust        : NULL
##   ..$ vjust        : NULL
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : NULL
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ legend.text.position            : NULL
##  $ legend.title                    :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : NULL
##   ..$ hjust        : num 0
##   ..$ vjust        : NULL
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : NULL
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi TRUE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ legend.title.position           : NULL
##  $ legend.position                 : chr "right"
##  $ legend.position.inside          : NULL
##  $ legend.direction                : NULL
##  $ legend.byrow                    : NULL
##  $ legend.justification            : chr "center"
```

```
##  $ legend.justification.top        : NULL
##  $ legend.justification.bottom     : NULL
##  $ legend.justification.left       : NULL
##  $ legend.justification.right      : NULL
##  $ legend.justification.inside     : NULL
##  $ legend.location                 : NULL
##  $ legend.box                      : NULL
##  $ legend.box.just                 : NULL
##  $ legend.box.margin               : 'margin' num [1:4] 0cm 0cm 0cm 0cm
##   ..- attr(*, "unit")= int 1
##  $ legend.box.background           : list()
##   ..- attr(*, "class")= chr [1:2] "element_blank" "element"
##  $ legend.box.spacing              : 'simpleUnit' num 11points
##   ..- attr(*, "unit")= int 8
##   [list output truncated]
##  - attr(*, "class")= chr [1:2] "theme" "gg"
##  - attr(*, "complete")= logi TRUE
##  - attr(*, "validate")= logi TRUE
```