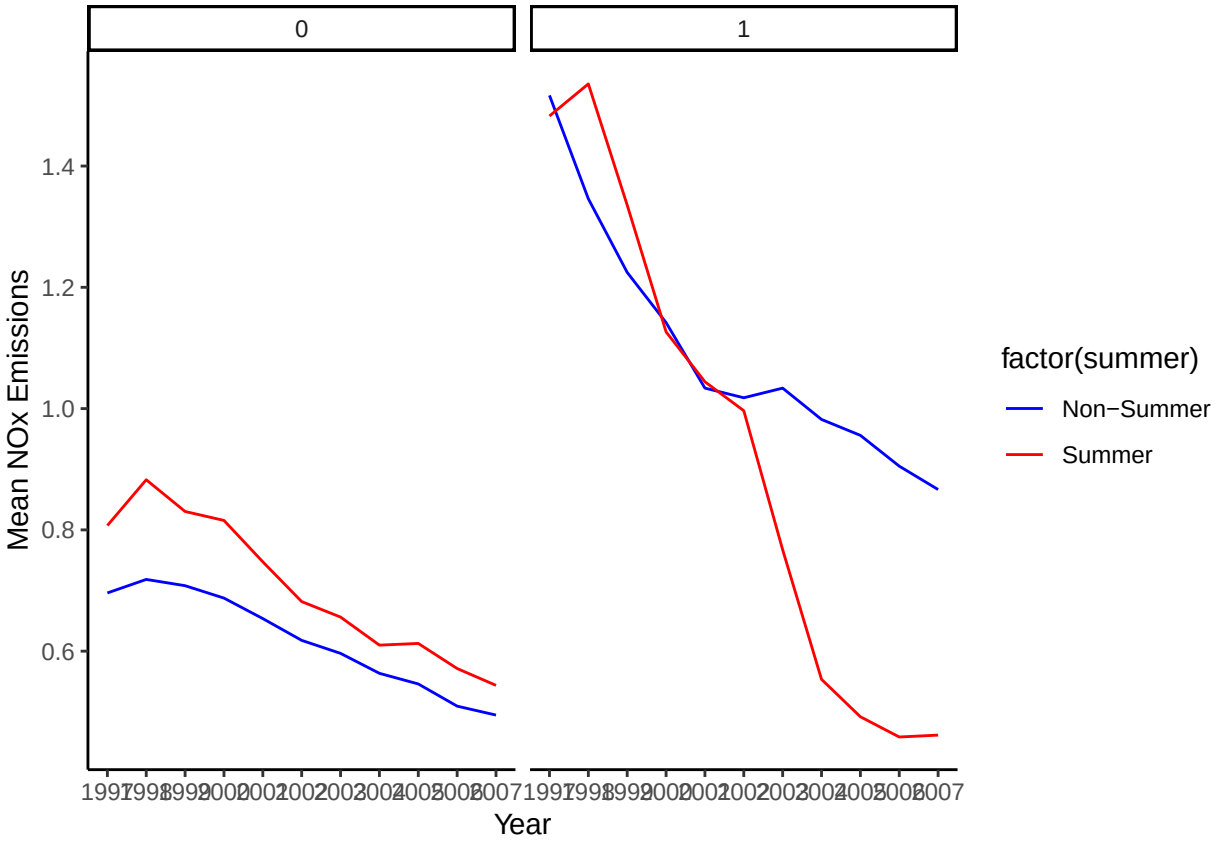
nox_project

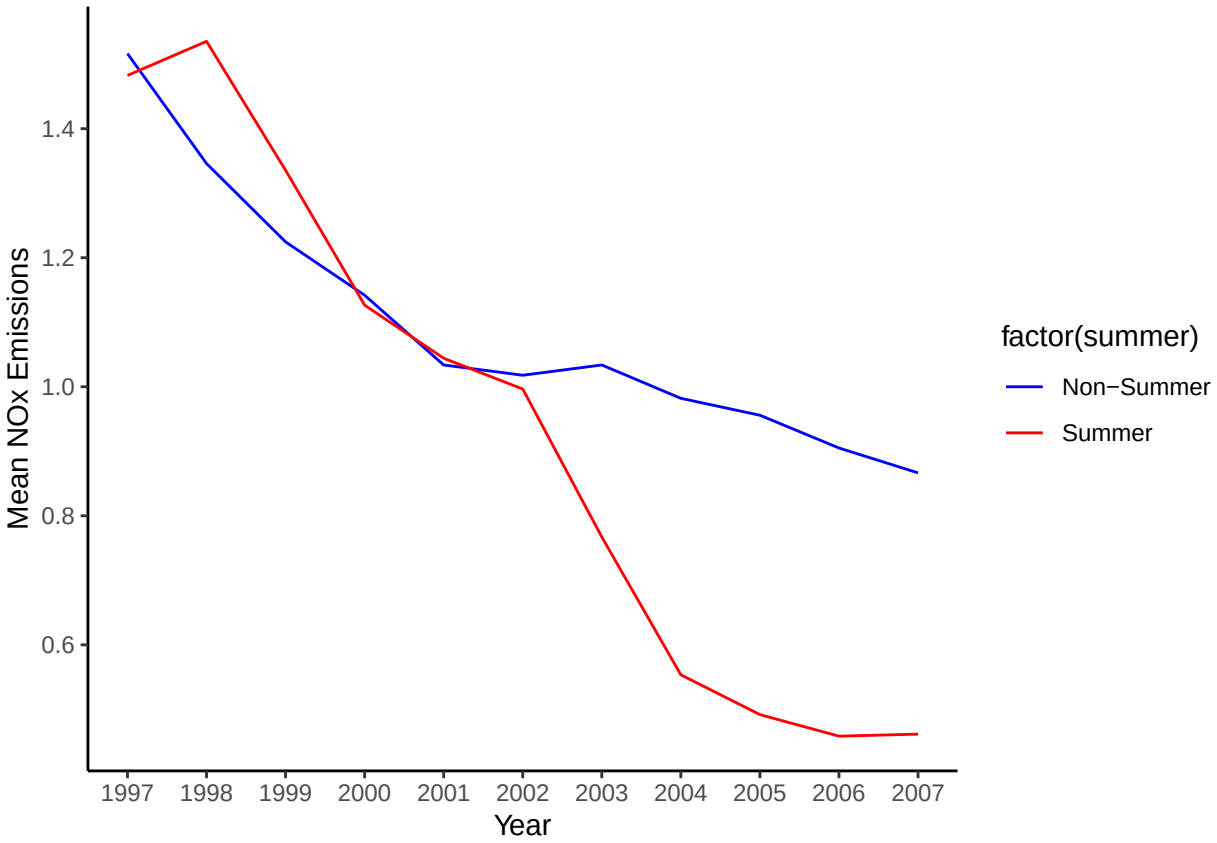
2024-04-02

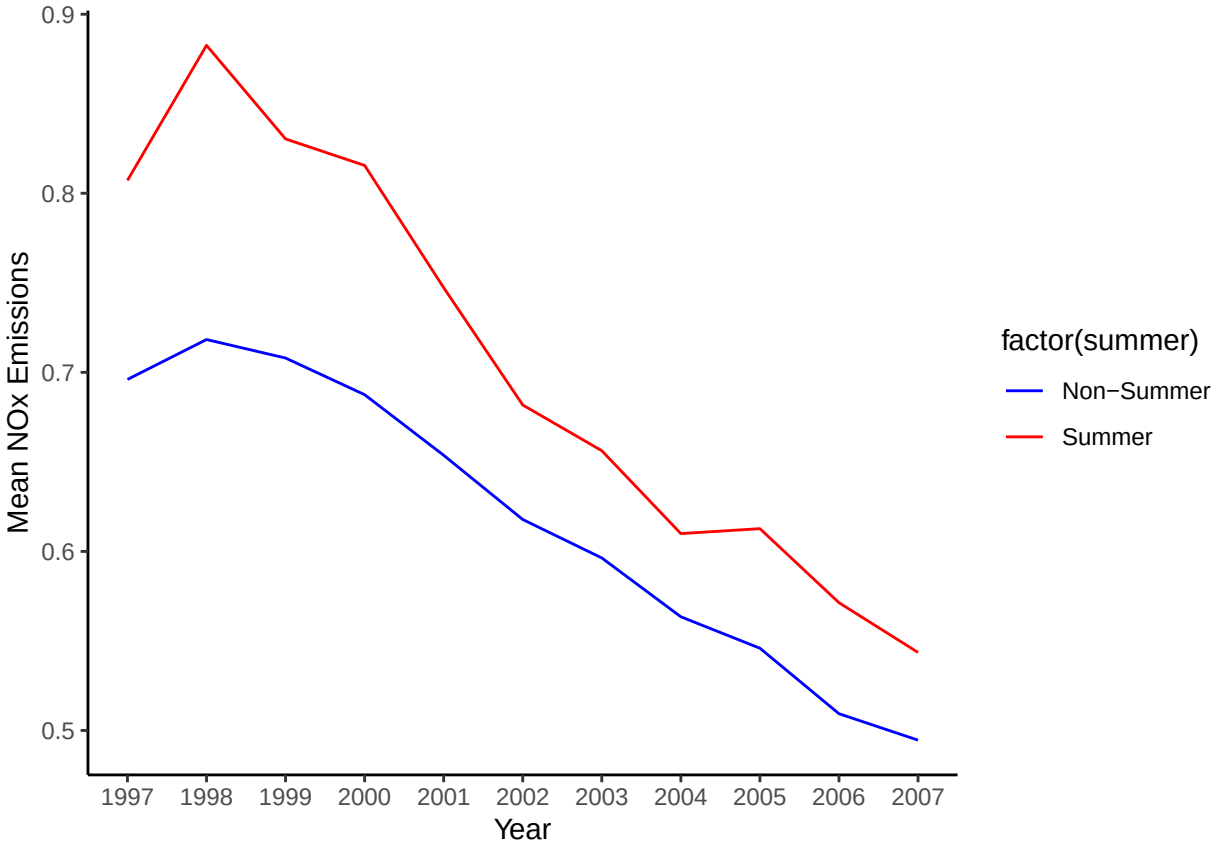
Variable “nbp” indicates whether or not the state was regulated by the NOx Budget Trading Program. “nbp” = 1 denotes that the state is regulated by the NBP program.

Variable “summer” indicates whether or not the observed time period was during summer months or during the off season. “summer” = 1 designates the observation occurred through summer months.

The variable “post” = 1 indicates that the time period of observation is post-treatment. For the purposes of this study, “post” = 1 denotes 2003 and following years.




Mean NOx Emissions
1.4
1.2
1.0
0.8
0.6
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year
factor(summer)
Non−Summer
Summer



The Parallel Trends assumption states that in the absence of the treatment or intervention being studied, the average outcomes of the treatment and control groups would follow parallel trends over time. In other words, before the treatment is introduced, the trends in outcomes for the treatment group and the control group should be similar or "parallel" to each other.

Based on visual observation, the parallel trends assumption is likely to hold given the corresponding graph of states not participating in the NBP program. This graph shows that the trend between summer and winter months remains approximately similar in states without "treatment" from participating in the NBP program.

Moreover, based on the regression design with output variable as 'nox_emit' and independent variables 'summer', 'year', and 'summer*year', we find the data upholds the parallel trends assumption. This is demonstrated in the summer*year variable being statistically insignificant. Here, the statistical insignificance represents no discernable change between summer and winter months during the pre-treatment period, demonstrating the parallel trends assumption holds.

The goal of panel 0 is to act as a placebo test. The non-NBP states function as a control to determine whether or not the NBP policy is effective. By creating a graph that compares emissions in non-NBP states in corresponding time periods, the research demonstrates that the NBP policy had an impact on NOx emissions, relative to both prior summertime emissions, and the 'control group' (non-NBP states).

```
## Warning: In lm.fit(x, y, offset = offset, singular.ok = singular.ok, ...) :
##  extra argument 'cluster' will be disregarded
```

```
##
## Call:
## lm(formula = nox_emit ~ summer + year + year:summer, data = nbp_pre_data,
##     cluster = "state_season_cluster")
```

```
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -0.952 -0.835 -0.723 -0.661 67.591
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 93.39940   29.40863   3.176  0.00150 **
## summer      23.52249   41.59008   0.566  0.57168
## year        -0.04634    0.01471  -3.151  0.00163 **
## summer:year -0.01173    0.02080  -0.564  0.57268
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.1 on 30464 degrees of freedom
## Multiple R-squared:  0.0009323,  Adjusted R-squared:  0.0008339
## F-statistic: 9.476 on 3 and 30464 DF,  p-value: 2.97e-06
```

```
##
## Call:
## lm(formula = nox_emit ~ summer + post + summer * post, data = nbp_data1)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -1.058 -1.024 -0.801 -0.461 67.485
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.02399    0.03835  26.703  < 2e-16 ***
## summer       0.03379    0.05423   0.623    0.533
## post        -0.22341    0.05688  -3.928 8.59e-05 ***
## summer:post -0.37317    0.08044  -4.639 3.51e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.233 on 26066 degrees of freedom
## Multiple R-squared:  0.005226,   Adjusted R-squared:  0.005112
## F-statistic: 45.65 on 3 and 26066 DF,  p-value: < 2.2e-16
```

```
## R^2= 0.00523
##
##                Estimate Std. Error    t value     Pr(>|t|)
## (Intercept)  1.02398535 0.13764276  7.4394420 1.011115e-13
## summer       0.03379278 0.19142963  0.1765285 8.598788e-01
## post        -0.22341472 0.02904456 -7.6921369 1.446976e-14
## summer:post -0.37316871 0.08886554 -4.1992512 2.677991e-05
```

The Difference in Difference Regression is defined as 'nox_emit' regressed on 'summertime' , 'post' , and the interaction term 'summer*post' . *This interaction term is defined as the effect of the NBP program post-2003, during the summer time. Our coefficient (-0.373169) on 'summer*post' indicates that the NBP program reduces the amount of NOx emissions in the observed periods post-2003 during the summer time.

```
## R^2= 0.00114
```

```
##
##                Estimate Std. Error    t value     Pr(>|t|)
## (Intercept)  0.50237864 0.08086628  6.2124611 5.216111e-10
## summer       0.08412564 0.13245908  0.6351066 5.253589e-01
## post        -0.10212768 0.03640671 -2.8051886 5.028715e-03
## summer:post -0.04215831 0.06579788 -0.6407245 5.217017e-01
```

The Difference in Difference Regression is again defined as 'nox_emit' regressed on 'summer' , 'post' , and the interaction term 'summer*post'* . *The difference in the regression lies in the data used. Previously, we used data with NBP-participating states. For this regression, we used non-NBP participating states. This interaction term is similarly defined as the effect of the NBP program post-2003 during the summer time. Our coefficient (-0.04215831) on 'summer*post' demonstrates a small effect on states in this dataset. This is expected given the non-NBP status of states in this regression.

```
full_nox_cluster_df
```

```
##                    Estimate Std..Error    t.value     Pr...t..
## (Intercept)      0.50237864 0.08039046  6.2492318 4.124763e-10
## summer           0.08412564 0.13167969  0.6388658 5.229103e-01
## post            -0.10212768 0.03619249 -2.8217921 4.775612e-03
## nbp              0.52160670 0.15862773  3.2882441 1.008144e-03
## summer:post     -0.04215831 0.06541072 -0.6445169 5.192403e-01
## summer:nbp      -0.05033286 0.23132267 -0.2175872 8.277507e-01
## post:nbp        -0.12128705 0.04628775 -2.6202839 8.785659e-03
## summer:post:nbp -0.33101040 0.10987882 -3.0125040 2.591020e-03
```

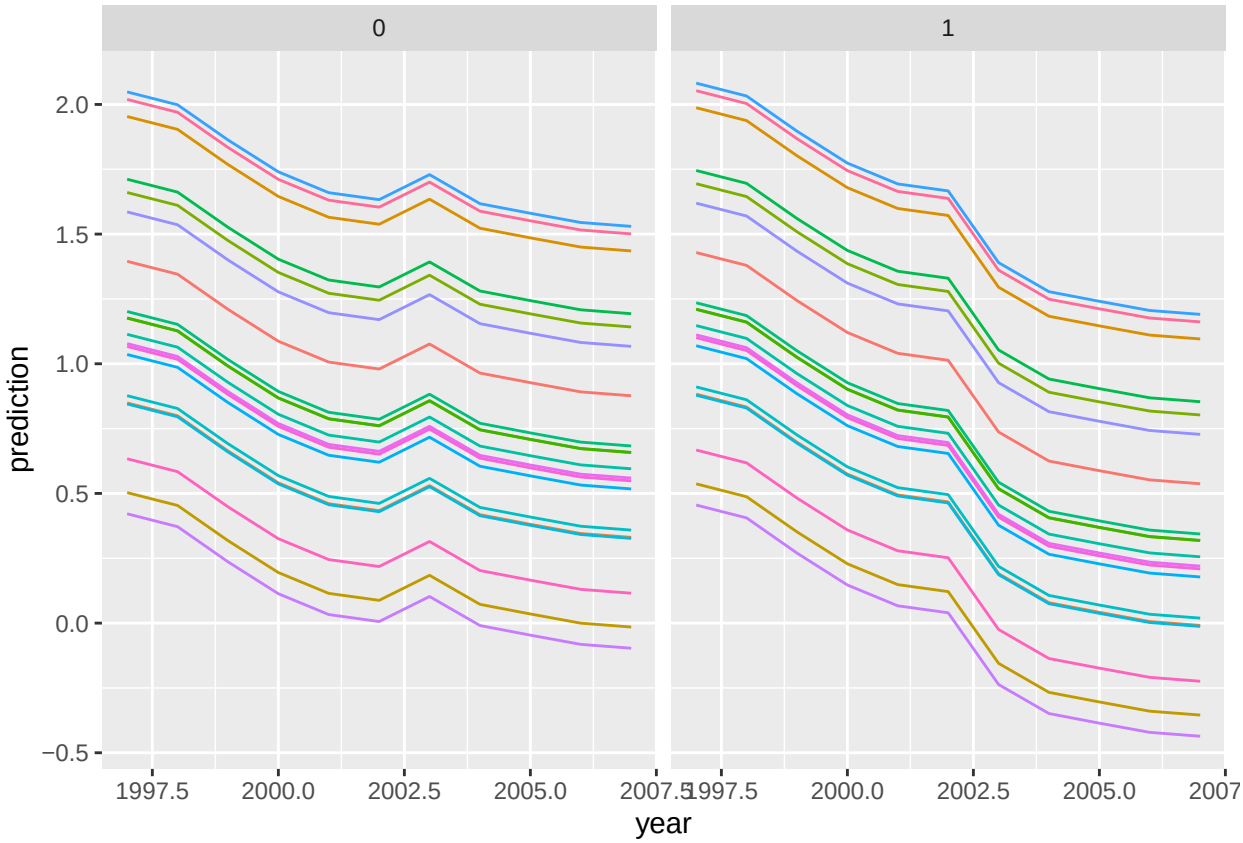
The Triple-Difference regression is defined as 'nox_emit' regressed on the variables 'summer' , 'post' , 'nbp' , and the interaction terms 'summer*post' , 'summer*nbp' , 'post*nbp' , and 'nbp*summer*post' . The interaction term 'nbp*summer*post' is similar to prior observed interaction terms, differing by accounting for the effect of NBP in summer post-treatment. The coefficient is also statistically different from 0 (-0.33101040, P-Value: 2.591020 e-3), meaning that for observations treated (nbp) post-treatment (post) during summertime (summer) there is a decline in NOx emissions.

```
summary(out)
```

```
##
## Call:
## lm(formula = nox_emit ~ summer * post + factor(fips_state) +
##     factor(year), data = nbp_data1, cluster = ~fips_state)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -2.082 -1.082 -0.696 -0.260 67.442
##
## Coefficients: (1 not defined because of singularities)
##                        Estimate Std. Error t value Pr(>|t|)
## (Intercept)             1.39514    0.10790  12.931  < 2e-16 ***
## summer                  0.03379    0.05378   0.628 0.529755
## post                   -0.51843    0.10132  -5.117 3.13e-07 ***
## factor(fips_state)9    -0.54618    0.25571  -2.136 0.032696 *
## factor(fips_state)10    0.55838    0.40342   1.384 0.166331
## factor(fips_state)11   -0.89189    0.68869  -1.295 0.195309
```

```
## factor(fips_state)17 -0.21922    0.10750  -2.039 0.041433 *
## factor(fips_state)18  0.26534    0.10979   2.417 0.015665 *
## factor(fips_state)21 -0.21843    0.10425  -2.095 0.036171 *
## factor(fips_state)24  0.31642    0.16262   1.946 0.051695 .
## factor(fips_state)25 -0.19365    0.20088  -0.964 0.335058
## factor(fips_state)26 -0.28163    0.11227  -2.508 0.012133 *
## factor(fips_state)34 -0.51811    0.17096  -3.031 0.002444 **
## factor(fips_state)36 -0.55000    0.12047  -4.566 5.00e-06 ***
## factor(fips_state)37 -0.35935    0.10793  -3.330 0.000871 ***
## factor(fips_state)39  0.65316    0.11084   5.893 3.84e-09 ***
## factor(fips_state)42  0.19047    0.11811   1.613 0.106829
## factor(fips_state)44 -0.97358    0.31692  -3.072 0.002128 **
## factor(fips_state)45 -0.31746    0.13090  -2.425 0.015305 *
## factor(fips_state)47 -0.32826    0.10906  -3.010 0.002616 **
## factor(fips_state)51 -0.76147    0.10254  -7.426 1.15e-13 ***
## factor(fips_state)54  0.62418    0.12438   5.018 5.25e-07 ***
## factor(year)1998     -0.04962    0.09314  -0.533 0.594213
## factor(year)1999     -0.18519    0.09314  -1.988 0.046795 *
## factor(year)2000     -0.30828    0.09314  -3.310 0.000935 ***
## factor(year)2001     -0.38861    0.09314  -4.172 3.03e-05 ***
## factor(year)2002     -0.41546    0.09314  -4.460 8.21e-06 ***
## factor(year)2003      0.19951    0.09314   2.142 0.032204 *
## factor(year)2004      0.08753    0.09314   0.940 0.347353
## factor(year)2005      0.05043    0.09314   0.541 0.588199
## factor(year)2006      0.01494    0.09314   0.160 0.872604
## factor(year)2007           NA         NA      NA       NA
## summer:post          -0.37317    0.07976  -4.678 2.91e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.206 on 26038 degrees of freedom
## Multiple R-squared:  0.02284,    Adjusted R-squared:  0.02168
## F-statistic: 19.63 on 31 and 26038 DF,  p-value: < 2.2e-16
```

```
plot4
```



The diff-in-diff-in-diff model re-estimated as a 2-Way Fixed Effect model gives us the same outcome coefficients on the summer*post variable. We get the same outcome because we are accounting for the idiosyncratic differences between states and years, similar to the difference in difference models which compare the treatment across groups and time. The 2-Way Fixed Effects model also captures this effect through the incorporation of the factor variables into the model. This is also demonstrated in 'plot4' as the treatment is equal across time in all groups. If there were differences in treatment implementation or at different points in time, the 2-Way Fixed Effects model would not accurately capture the effect of treatment across groups or time.