ARE 261-B PS 1 (Shapiro)

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1 Replication of Figure 1

We wish to replicate Figure 1 from Deschênes et al. (2017), which depicts total average daily NO_x emissions from all NBP-participating states in 2001-2002 compared to 2005-2007. **Since Missouri only joined the NBP market in 2007, Missouri is considered a non-NBP state for the purposes of this analysis.**

These estimates are obtained from an OLS regression of NO_x emissions on six day-of-week indicators and a constant. The values in the graph equal the constant plus the regression residuals, so that the graph depicts fitted values for the reference category (Wednesday).

1.1 Data

Data for NO_x emssions in 2002 and 2005 for states participating in the EPA's Nitrogen Oxides (NO_x) Budget Program (NBP) were downloaded from the EPA's Air Markets Program Data database. Facilities missing NO_x data for a given day that also had measured Operating Time of 0 are assumed to have 0 NO_x emissions for that day.

1.2 Total Daily Average NO_x Emissions

Figure 1 depicts total daily average NO_x emissions over the year, comparing 2002 to 2005 emissions from NBP-participating states as pre- and post-treatment observations. Even as a simple comparison, there's a dramatic affect on NO_x emissions during the days of the year when the NBP-participating states are required to restrict their emissions.

2 Polynomial regression discontinuity

2.1 The econometric equation

To examine the NBP effect on the Eastern states in 2005 (a treatment on the treated estimate), we consider only emissions from Eastern states (those participating in the NBP) in 2005 so I suppress the redundant y subscript on $NOx_{s,d,y}$ (all will have $y = 2005$).

$$NOx_d = \beta_0 + \beta_1 \cdot d + \beta_2 \cdot d^2 + \tau D_d + \varepsilon_d \tag{1}$$

where

$$\begin{aligned}
d &= \text{day of the year} \in \{1, 2, ..., 365\} \\
D_d &= \text{ozone season indicator; 1 if } d \in [121,\ 273] \text{ (the ozone season*)} \\
NOx_d &= \frac{1}{20} \sum_{s \in East} NOx_{s,d,2005} \\
&= \text{sum of average daily NO}_x\text{emissions from the 20 NBP states on day } d \\
NOx_{s,d,y} &= \text{average daily NO}_x\text{emissions from NBP state } s \text{ on day } d \text{ in year } y
\end{aligned}$$

*The ozone season is May-September. May 1^{th} is the 121^{st} day of the year and September 30^{th} is the 273^{rd} day of the year, in non-leap years.

2.2 Polynomial Regression Discontinuity estimates at the beginning and end of the season

The first specification of the polynomial regression discontinuity is estimating the discontinuity around the beginning of the ozone season – estimating the impact of the restrictions turning on on May 1st. Column 1 of Table 1 show the estimation of equation (1) after restricting the data to a 2-month window around the beginning of the policy in 2005 (April-May). The estimated effect of imposing the restrictions of the NO_x Budget Trading Program in May 2005 was a reduction in NO_x emissions of about 2.069 thousand tons.

The second specification of the polynomial regression discontinuity is estimating the discontinuity around the end of the ozone season – estimating the impact of the restrictions turning off on October 1st. Column 2 of Table 1 show the estimation of equation (1) after restricting the data to a 2-month window around the end of the policy in 2005 (September-October). The estimated effect of removing the restrictions of the NO_x Budget Trading Program in October 2005 was an increase in NO_x emissions of about -2.499 thousand tons.

2.3 Inference and weighting in the polynomial RD

Because I have aggregated the data to the day-year-state level, the regression of NO_x emissions on day-of-year and the regulation indicator implicitly weights each state equally. The above results should then be interpreted as a reduction (increase) of 2069 tons (-2499 tons) of NO_x emissions in the average NBP state at the start (end) of the regulation season. We could instead rewight the regression using the number of firms in each state and interpret the estimated effects as an reduction or increase in the average firm's NO_x emissions.

3 Spline Regression Discontinuity

3.1 The econometric equation

$$NOx_d = \beta_0 + \beta_1\ d + \beta_2\ d^2 + \beta_3\ d\ D_d + \beta_4\ d^2\ D_d + \tau\ D_d + \varepsilon_d \tag{2}$$

where

$$\begin{aligned}
d &= \text{day of the year (an integer between 1 and 365)} \\
D_d &= \text{ozone season indicator; 1 if } d \in [121,\ 273] \text{ (the ozone season*)} \\
NOx_d &= \frac{1}{20} \sum_{s \in East} NOx_{s,d,2005} \\
&= \text{sum of average daily NO}_x\text{emissions from the 20 NBP states on day } d \\
NOx_{s,d,y} &= \text{average daily NO}_x\text{emissions from NBP state } s \text{ on day } d \text{ and year } y
\end{aligned}$$

*The ozone season is May-September. May 1$^{\text{th}}$, 2005 is the 121$^{\text{st}}$ day of the year and September 30$^{\text{th}}$, 2005 is the 273$^{\text{rd}}$ day of the year.

3.2 Spline Regression Discontinuity estimates at the beginning and end of the season

The first specification of the spline regression discontinuity is estimating the discontinuity around the beginning of the ozone season – estimating the impact of the restrictions turning on on May 1st. Column 3 of Table 1 show the estimation of equation (2) after restricting the data to a 2-month window around the beginning of the policy in 2005 (April-May). The estimated effect of imposing the restrictions of the NO_x Budget Trading Program in May 2005 was a reduction in NO_x emissions of about 1.835 thousand tons.

The second specification of the spline regression discontinuity is estimating the discontinuity around the end of the ozone season – estimating the impact of the restrictions turning off on October 1st. Column 2 of Table 1 show the estimation of equation (2) after restricting the data to a 2-month window around the end of the policy in 2005 (September-October). The estimated effect of removing the restrictions of the NO_x Budget Trading Program in October 2005 was an increase in NO_x emissions of about -2.783 thousand tons.

4 Cross-Sectional Comparison

4.1 The econometric equation

To examine the NBP effect on the Eastern states in 2005 (a treatment on the treated estimate), we consider only emissions from Eastern states (those participating in the NBP) in 2005 so I suppress the redundant y subscript on $NOx_{s,d,y}$ (all will have $y = 2005$).

$$NOx_{s,o} = \beta + \tau \; D_o + \varepsilon_{s,o} \tag{3}$$

where

$$\begin{aligned}
s &= \text{state (of NBP participating states)} \\
o &= \text{ozone season (Summer or Winter*)} \\
D_o &= \text{ozone season indicator; 1 if } o = \text{Summer} \\
NOx_{s,o} &= D_o \frac{1}{153} \sum_{d \in o} NOx_{s,d,2005} + (1 - D_o) \frac{1}{212} \sum_{d \in o} NOx_{s,d,2005} \\
&= \text{season mean average daily NO}_x\text{emissions from NBP state } s \\
NOx_{s,d,y} &= \text{average daily NO}_x\text{emissions from NBP state } s \text{ on day } d \text{ and year } y
\end{aligned}$$

*The ozone season is May-September, so I am calling Summer May-September, and Winter is Jan-April and October-December.

4.2 Cross Sectional estimates for ozone-season average daily emissions

The cross-sectional specification is estimating the effects of the NBP on average daily emissions across states, where daily emissions are averaged at the state-ozone-season level – estimating the impact of the restrictions being on all Summer. Column 1 of Table 2 show the estimation of equation (3) after restricting the data to NBP-participating states in 2005. The estimated average effect of imposing the restrictions of the NO_x Budget Trading Program in 2005 was a reduction in daily NO_x emissions of about 1.644 tons per state.

5 Pre/post differences-in-differences

5.1 The econometric equation

To examine the pre-post NBP effect on the Eastern states (a treatment on the treated estimate), we consider only emissions from Eastern states (those participating in the NBP) so I suppress the redundant r subscript (all will have $r = East$).

$$NOx_{d,y} = \beta_0 + \beta_1 \mathbf{1}\{y = 2005\} + \beta_2 \mathbf{1}\{d \in \text{Ozone Season}\} + \tau D_{d,y} + u_y + \varepsilon_{d,y} \tag{4}$$

where

$$\begin{aligned}
d &= \text{day of the year} \in \{1, 2, ..., 365\} \\
y &= \text{year} \in \{2002, 2005\} \\
\text{Ozone Season} &= [121, 273] \cap \mathbb{N};\ \text{days of the year in the NBP season} \\
D_{d,y} &= \text{NBP participation indicator; 1 if } y = 2005 \ \&\ d \in \text{Ozone Season} \\
NOx_{d,y} &= \frac{1}{20} \sum_{s \in East} NOx^*_{s,d,y} \\
&= \text{region-mean average daily NO}_x\text{emissions from states in the East on day } d \text{ in year } y \\
NOx_{s,d,y} &= \text{average daily NO}_x\text{emissions from all units in NBP state } s \text{ on day } d \text{ in year } y
\end{aligned}$$

*The states considered Eastern are those 20 states participating in the NBP (including the District of Columbia).

5.2 Pre/post Diff-in-Diff estimates for East

The pre-post differences-in-differences specification is estimating the effects of the NBP on total regional daily emissions across the entire NBP region, where daily emissions are totaled at the region-day level. Column 1 of Table 3 shows the estimation of τ in equation (4) after restricting the data to NBP-participating states in both 2002 (pre) and 2005 (post). The estimated average effect of imposing the restrictions of the NO_x Budget Trading Program in the NBP region was a reduction in Eastern regional daily NO_x emissions of about `r -round(pre_post_coef, 3)` thousand tons. This assumes that the 2002 NBP region and 2005 NBP region have similar untreated NO_x trends.

6 East/west differences-in-differences

6.1 The econometric equation

To examine the East-West NBP effect in 2005, we consider only emissions from states in 2005, so I suppress the redundant y subscript (all will have $y = 2005$).

$$NOx_{d,r} = \beta_0 + \beta_1 \mathbf{1}\{d \in \text{Ozone Season}\} + \beta_2 \mathbf{1}\{r = East\} + \tau D_{d,r} + u_r + \varepsilon_{d,r} \tag{5}$$

where

$$\begin{aligned}
d &= \text{day of the year} \in \{1, 2, ..., 365\} \\
r &= \text{region of the US} \in \{East, West\}^{*} \\
\text{Ozone Season} &= [121, 273] \cap \mathbb{N};\ \text{days of the year in the NBP season} \\
D_{d,r} &= \text{NBP participation indicator; 1 if } r = East \ \&\ d \in \text{Ozone Season} \\
NOx_{d,r} &= \frac{1}{|r|} \sum_{s \in r} NOx_{s,d,2005} \\
&= \text{region-mean average daily NO}_x\text{emissions from } |r| \text{ states in region } r \text{ on day } d \text{ in year 20} \\
NOx_{s,d,y} &= \text{average daily NO}_x\text{emissions from all units in NBP state } s \text{ on day } d \text{ in year } y
\end{aligned}$$

*The states considered Eastern are those 20 states participating in the NBP (including the District of Columbia). Western states are non-NBP participating states, excluding Alaska and Hawaii; a total of 50 + 1 (D.C.) - 2 (AK, HI) - 20 (Eastern) = 29 states.

6.2 East/West Diff-in-Diff estimates for 2005

The East-West differences-in-differences specification is estimating the effects of the NBP on total regional daily emissions across the entire NBP region, where daily emissions are totaled at the region-day level. Column 2 of Table 3 shows the estimation of τ in equation (5) after restricting the data to 2005 in both East (NBP) and West (non-NBP) states. The estimated average effect of imposing the restrictions of the NO_x Budget Trading Program in 2005 was a reduction in Eastern regional daily NO_x emissions of about 3.323 thousand tons. This assumes that the East and West regions have similar untreated NO_x trends.

7 Differences-in-differences-in-differences

7.1 The econometric equation

$$\begin{aligned} NOx_{d,y,r} &= \beta_0 + \beta_1 \mathbf{1}\{y = 2005\} + \beta_2 \mathbf{1}\{d \in \text{Ozone Season}\} + \beta_3 \mathbf{1}\{r = East\} \\ &+ \beta_4 \mathbf{1}\{y = 2005 \ \& \ d \in \text{Ozone Season}\} + \beta_5 \mathbf{1}\{y = 2005 \ \& \ r = East\} \\ &+ \beta_6 \mathbf{1}\{d \in \text{Ozone Season} \ \& \ r = East\} + \tau D_{d,y,r} + u_{y,r} + \varepsilon_{d,y,r} \end{aligned} \tag{6}$$

where

$$\begin{aligned} r &= \text{region of the US} \in \{East, West\}^* \\ d &= \text{day of the year} \in \{1, 2, ..., 365\} \\ y &= \text{year} \in \{2002, 2005\} \\ \text{Ozone Season} &= [121, 273] \cap \mathbb{N};\ \text{days of the year in the NBP season} \\ D_{d,y,r} &= \text{NBP participation indicator; 1 if } y = 2005 \ \& \ d \in \text{Ozone Season} \ \& \ r = East \\ NOx_{d,y,r} &= \frac{1}{|r|} \sum_{s \in r} NOx_{s,d,y} \\ &= \text{region-mean average daily NO}_x\text{emissions from states in region } r \text{ on day } d \text{ in year } y \\ NOx_{s,d,y} &= \text{average daily NO}_x\text{emissions from all units in NBP state } s \text{ on day } d \text{ in year } y \end{aligned}$$

*The states considered Eastern are those 20 states participating in the NBP (including the District of Columbia). Western states are non-NBP participating states, excluding Alaska and Hawaii; a total of 50 + 1 (D.C.) - 2 (AK, HI) - 20 (Eastern) = 29 states.

7.2 Triple differences estimates over season, year, and region

The triple differences-in-differences specification is estimating the effects of the NBP on total regional daily emissions across the entire NBP region, where daily emissions are totaled at the region-day level. Column 3 of Table 3 shows the estimation of τ in equation (6). The estimated average treatment effect of imposing the restrictions of the NO_x Budget Trading Program was a reduction in Eastern regional daily NO_x emissions of about 2.687 thousand tons.

7.3 Inference and weighting in triple differences

Since there are more states in the Western region (29 vs. 20), and we are comparing regional average emissions, we are implicitly weighting the Eastern region states more than the Western region states – we are comparing regional changes. If we wanted to estimate effects on the average state, we could weight the regression using weights proportional to the inverse of the number of states in each region. We could also re-weight to estimate the average unit effect.

Similarly, since there are only 120 days before the NBP season and 153 days in the NBP season, we are implicitly putting more weight on the days before the season starts than on the days during the season – we estimating average season daily changes. If we were interested in the effect on an average day, we could re-weight proportional to the inverse of the number of days in the season (May-Sept vs. Oct-April).

I choose to leave the regressions unweighted because it makes the analysis clear – the NO_x Budget Trading Program reduced the Eastern regional daily NO_x emissions by about 2.687 thousand tons. If we are asking serious questions about climate change, the regional level is a fine level to investigate policy implications. If we believe this is close to the true estimate, and we think this is externally valid and can be applied to the rest of the US, we could estimate first-order affects of a national program by scaling up by the ratio of total US NO_x emissions that would be regulate to total eastern NO_x emissions currently being regulated. This of course ignores spillover and interaction effects between the regions in the market – the market will now have many more participants and could become more efficient at allocating budgeted emissions to firms with higher marginal costs.

Inference of the NBP treatment effect based on τ in Equation (6) hinges on the assumption that, to the extent that NO_x has different trends in the Eastern region than the Western region, the differences affect the emissions in the non-ozone and ozone seasons similarly. That seems fairly credible since both regions include major coastal cities and overlap most of their range of latitude (which would affect seasonality).

Because we are using region-level data, the standard errors are already clustered at the region level, which is desired because that is our level of policy analysis.

8 Discussion of Estimators

8.1 Internal Validity

Assume NO_x trends differ between the eastern and western regions – then, for internal validity of $\hat{\tau}$ from (6), we need that those trends differ similarly for non-ozone and ozone seasons. So we should concern ourselves with differences between the regions and seasons causing the difference between seasons to trend differently between the regions (aside from the effect of the program). For example, if something happened in the summer of 2005 in the eastern region to change the NO_x emissions, it would pose a threat to internal validity. This is a rather obvious statement – an event that co-occurs with our treatment is, of course, going to confound our treatment.

Leakage is a large concern here if NO_x-producing firms have the ability to transfer production to non-NBP states between the start of the NBP program in 2003 and the NBP season in 2005 – we will be over-estimating the effects of the program because the difference between eastern and western states will be artificially larger since NO_x is moving from eastern states to western. This could possibly happen only during the summer periods when the NBP is operating due to market pressures – the higher production costs during that time lead real-time prices to be higher, so some firms using products produced by NO_x-emitting firms will choose to import those products from other states if the cost of transport plus the cost of the item is lower than than the increases summer price of the product within the NBP state.

8.2 Preferred Specification

Of the methods presented to estimate the effect of the NBP program, I prefer the triple differences approach. Since I do not have any control variables, the other specifications almost surely suffer from sever omitted variable bias. Triple differences is robust to much OVB because it differences out any year-invariant, unit-invariant, and season-invariant unobserved variables that may be correlated with the treatment. The eastern states over the summer period in 2005 is still a very large unit of treatment that could be different from the western region during summer of 2005 for many reasons, but given the nature of the program, I believe this is the best estimator of the NBP effects (of the selection presented here).

9 EPA emissions caps

If the EPA announced caps on emissions for the NBP years, why not just simply use those caps as a measure of NO_x emissions reductions? Many firms banked their allowances for future years, so it is unclear which years' emissions are being affected by a single year's cap.

10 First-order Conditions for the Consumer

Let $s(c, a)$ be the number of hours per week spent sick by a consumer, which depend on

c, the concentration of pollution being faced, and
a, the amount of defensive behavior chosen

Then the consumer maximizes their utility by choosing the amount of a numeraire good X, leisure hours f, and defensive behavior a to purchase (and by elimination, the amount they work), subject to their budget constraint:

$$\max_{X,f,a} u(X, f, s(c, a)) \quad s.t. \quad I + p_w(T - f - s) \geq X + p_a a$$

so the first-order conditions for the consumer result from derivatives of X, f, and a:

$$\mathcal{L} = u(X, f, s(c, a)) + \lambda(I + p_w(T - f - s(c, a)) - X - p_a a)$$

$$\text{(FOC1)} \quad \frac{\partial \mathcal{L}}{\partial X} = \frac{\partial u}{\partial X} - \lambda = 0$$
$$\implies \frac{\partial u}{\partial X} = \lambda$$

$$\text{(FOC2)} \quad \frac{\partial \mathcal{L}}{\partial f} = \frac{\partial u}{\partial f} - \lambda p_w = 0$$
$$\implies \frac{\partial u}{\partial f} = \lambda p_w = \frac{\partial u}{\partial X} p_w$$

$$\text{(FOC3)} \quad \frac{\partial \mathcal{L}}{\partial a} = \frac{\partial u}{\partial a} - \lambda p_w \frac{\partial s}{\partial a} - \lambda p_a = \frac{\partial u}{\partial s}\frac{\partial s}{\partial a} - \lambda p_w \frac{\partial s}{\partial a} - \lambda p_a = 0$$
$$\implies \frac{\partial u}{\partial s} = \lambda \left(p_w + p_a \left(\frac{\partial s}{\partial a} \right)^{-1} \right)$$
$$\implies \frac{1}{\lambda}\frac{\partial u}{\partial s} = \left(p_w + p_a \left(\frac{\partial s}{\partial a} \right)^{-1} \right)$$

$$\text{(FOC4)} \quad \frac{\partial \mathcal{L}}{\partial \lambda} = I + p_w(T - f - s(c, a)) - X - p_a a = 0$$
$$\implies I + p_w(T - f - s(c, a)) = X + p_a a$$

Since X is the numeraire good, (FOC1) can be interpreted as the consumer chooses to maximize their utility by increasing X until their marginal utility from another unit of X is equal to the shadow price of increasing their budget (which is measured in units of X since it's the numeraire good).

(FOC2) tells us the consumer increases their amount of leisure hours until their marginal utility of leisure is equal to their wage rate times the shadow price of increasing their budget. Because they need to satisfy all FOCs, we know from (FOC1) that, at the optimum, λ will be the marginal utility of X. Thus, to maximize their utility, the consumer will increase their leisure until it equals the relative wage times the marginal utility of X (the relative wage p_w is the number of hours they need to work to purchase one unit of X). So this means: only take more leisure until another hour of leisure would cost you the utility gained from the amount of X consumed paid for by one hour's wages.

(FOC3) is telling us that the rate of substitution between sick hours and X is, at the optimal, equal to the difference between the relative wage rate and the cost of a sick day averted through purchase of defensive behavior (both in numeraire terms). Since $\partial u/\partial s < 0$, the cost of avoiding a sick day through defensive behavior must be larger in magnitude than the relative wage rate.

(FOC4) just gives us the budget constraint back – if the budget constraint is binding (which we would expect if the utility is convex), then we expect this to hold and to get an interior solution to the maximization problem.

Effect of pollution concentration on sickness (Eq. 2)

Taking the total derivative of the health production function $s(c, a)$ with respect to pollution concentration c, we get

$$\frac{ds}{dc} = \frac{\partial s}{\partial c} + \frac{\partial s}{\partial a}\frac{\partial a}{\partial c}$$

Rearranging, we get equation (2)

$$\frac{\partial s}{\partial c} = \frac{ds}{dc} - \frac{\partial s}{\partial a}\frac{\partial a}{\partial c}$$

11 Interpretation of derivatives of s

The total derivative of time spent sick s with respect to pollution concentration c – $\frac{ds}{dc}$ – is the sum of the direct effect of increased pollution on the number of sick days a consumer takes ($\frac{\partial s}{\partial c}$) and the indirect affect that changing defensive behavior in reaction to increased pollution has on sick days ($\frac{\partial s}{\partial a}\frac{\partial a}{\partial c}$). Here, $\frac{\partial s}{\partial a}$ represents the change in sick days as we increase our defensive behavior (we would expect $\frac{\partial s}{\partial a} < 0$). If pollution increases, it would make sense if a consumer chose to increase the amount they spent on defensive behaviors (increasing the amount of asthma medication they take on a smoggy day) so it might be safe to assume $\frac{\partial a}{\partial c} > 0$. This increase in defensive behavior has a mitigating effect on sick days (hopefully!).

It is hard to get data on people's defensive behavior: How many breaths of their inhaler did they take each day; how long did people spend outside vs inside and what is the difference in pollution concentration between outside and inside; how many days of work did someone skip because they wanted to protect their health (skipped as a preventative measure, which would be hard to disentangle from people taking sick days because they are made sick due to pollution). To measure $\frac{\partial s}{\partial a}$, we would need to see how the number of sick days change as people use different amounts of defensive behaviors, while keeping concentration constant, or have good data on an exogenous shock to people's ability to enage in those behaviors and the actual data on the behaviors themselves.

12 Marginal Willingness to Pay for Clean Air

The marginal willingness to pay for clean air is the negative of the marginal willingness to pay for an increase in pollution concentration c. The MWTP for an increase in pollution would be $\frac{\partial \mathcal{L}}{\partial c}$ (in utils), so dividing by λ lets us translate to dollars. Thus the marginal willingness to pay for clean air is

$$\begin{aligned} MWTP &= -\frac{1}{\lambda}\frac{\partial \mathcal{L}}{\partial c} \\ &= -\frac{1}{\lambda}\left[\frac{\partial \mathcal{L}}{\partial u}\frac{\partial u}{\partial s}\frac{\partial s}{\partial c} + \frac{\partial \mathcal{L}}{\partial s}\frac{\partial s}{\partial c}\right] \quad \text{by the Envelope Theorem} \end{aligned}$$

$\frac{\partial \mathcal{L}}{\partial u} = 1$ and $\frac{\partial \mathcal{L}}{\partial s} = -\lambda p_w$, so

$$\begin{aligned} &= -\frac{1}{\lambda}\left[\frac{\partial u}{\partial s}\frac{\partial s}{\partial c} - \lambda p_w \frac{\partial s}{\partial c}\right] \\ &= -\frac{1}{\lambda}\frac{\partial u}{\partial s}\frac{\partial s}{\partial c} + p_w\frac{\partial s}{\partial c} \\ &= -\frac{1}{\lambda}\frac{\partial u}{\partial s}\left(\frac{ds}{dc} - \frac{\partial s}{\partial a}\frac{\partial a}{\partial c}\right) + p_w\frac{\partial s}{\partial c} \quad \text{by Eq. (2)} \\ &= -\frac{1}{\lambda}\frac{\partial u}{\partial s}\frac{ds}{dc} + \frac{1}{\lambda}\frac{\partial u}{\partial s}\frac{\partial s}{\partial a}\frac{\partial a}{\partial c} + p_w\frac{\partial s}{\partial c} \\ &= -\frac{1}{\lambda}\frac{\partial u}{\partial s}\frac{ds}{dc} + \left(p_w + p_a\left(\frac{\partial s}{\partial a}\right)^{-1}\right)\frac{\partial s}{\partial a}\frac{\partial a}{\partial c} + p_w\frac{\partial s}{\partial c} \quad \text{by (FOC3)} \end{aligned}$$

then grouping the p_w terms

$$\begin{aligned} &= -\frac{1}{\lambda}\frac{\partial u}{\partial s}\frac{ds}{dc} + p_w\left(\frac{\partial s}{\partial a}\frac{\partial a}{\partial c} + \frac{\partial s}{\partial c}\right) + p_a\left(\frac{\partial s}{\partial a}\right)^{-1}\frac{\partial s}{\partial a}\frac{\partial a}{\partial c} \\ &= -\frac{1}{\lambda}\frac{\partial u}{\partial s}\frac{ds}{dc} + p_w\frac{ds}{dc} + p_a\frac{\partial a}{\partial c} \quad \text{by Eq. (2)} \end{aligned}$$

13 Price of defensive behavior

p_a describes the relative unit cost of avoiding pollution or adapting to pollution (defensive behavior). This is relative to the numeraire good in the model, which means it would be a trade off between spending income on a defensive behavior (medication) or on "other consumption". Other consumption is hard to measure when you just have data on the medications people are taking.

Two more issues that remain are: (1) complete measurement of various defensive behaviors; and (2) accurate measurement of the cost of a particular behavior to the consumer. For (1), we might consider a smokey day in the Bay area. There are many ways to defend against smokey air – staying inside, asthma medication, purchasing air filter masks, purchasing indoor air purifiers to increase the quality of the indoor air. If we only measure one, we may be missing other important defensive behaviors and mis-measure the aggregate price of defensive behaviors. Fro (2), the paper provides a useful example of medication costs – if we examine sticker prices of medications, we will most likely be overestimating the cost to the consumer because many consumers have insurance that will pay for a large portion of the price.

14 Figures

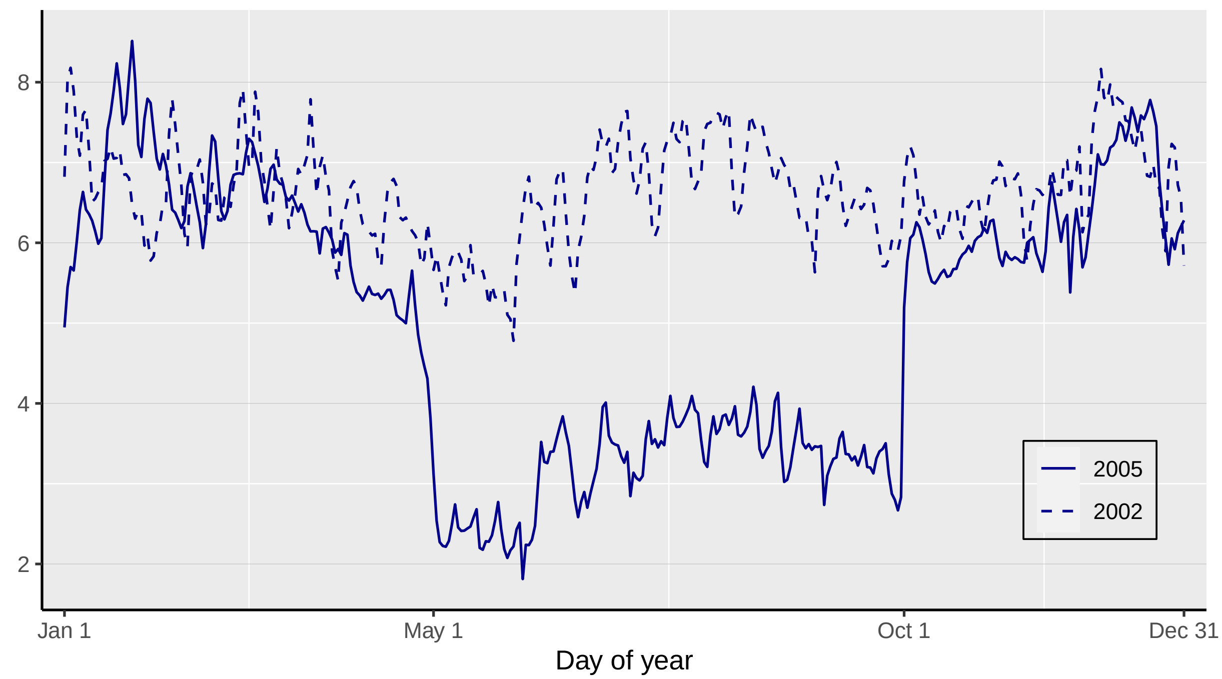

Figure 1: Total Daily nox Emissions in the NBP-Participating States

Notes: Figure 1 shows total average daily NO_x emissions (in 1000's of Tons) in the NBP participating states in 2002 and 2005. These estimates are obtained from an OLS regression of NO_x emissions on six day-of-week indicators and a constant. The values in the graph equal the constant plus the regression residuals, so that the graph depicts fitted values for the reference category (Wednesday). Total daily NO_x emissions on y-axis are measured in thousands of tons. The sample includes emissions from all the Acid Rain Units. NBP participating states include: Alabama, Connecticut, Delaware, Illinois, Indiana, Kentucky, Maryland, Massachusetts, Michigan, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, West Virginia, and the District of Columbia (Missouri did not join the market until 2007). Facilities missing NO_x data for a given day that also had measured Operating Time of 0 are assumed to have 0 NO_x for that day. This slightly affects the regression of NO_x on the day-of-week indicators, but results in very little difference in total sums of daily average NO_x emissions.

Table 1: NBP Polynomial Regression Discontinuity Results for 2005

	Total Daily Emissions (1000 tons)			
	NBP Start (May)	NBP End (Sepember)	NBP Start (May)	NBP End (Sepember)
Ozone Season Indicator	−2.069***	2.499***	−1.835***	2.783***
	(0.162)	(0.206)	(0.234)	(0.311)
Separate Time Trend?	No	No	Yes	Yes
Observations	61	61	61	61
Adjusted R^2	0.955	0.913	0.959	0.912
Note:				*p<0.1; **p<0.05; ***p<0.01

Notes: The "Separate Time Trend?" row in Table 1 represents whether or not the regression discontinuity included separate time trends for while the NBP program was running and when it was not.

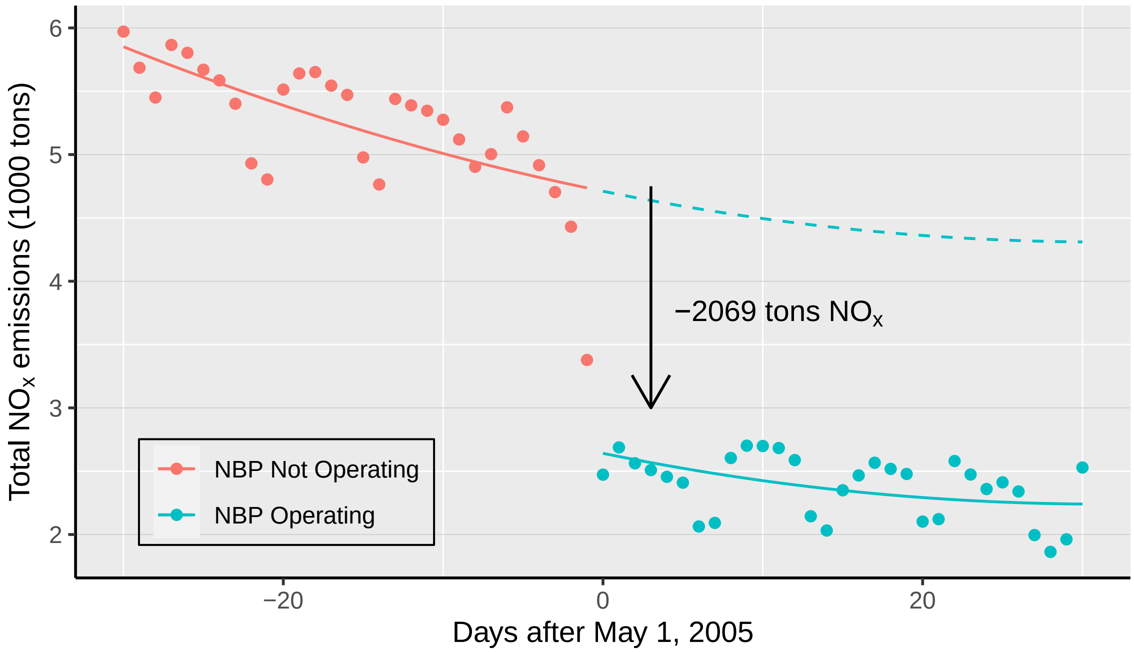

Figure 2: Regression Discontinuity plot with quadratic time trend for beginning of 2005 NBP season (constant shift only). The dependent variable is total average daily NO$_x$ emissions (in 1000's of Tons) in the NBP participating states in April and May, 2005. The fitted RDD lines use a quadratic time trend, with shared time trend parameters on either side of the discontinuity – only the regression intercept term differs on either side.

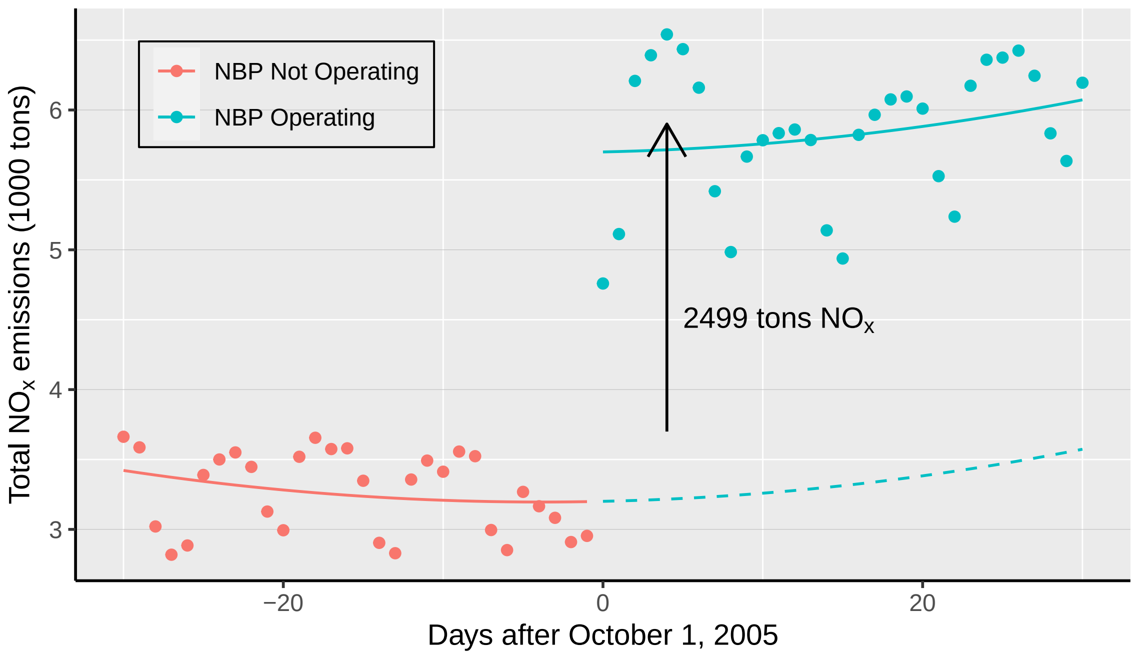

Figure 3: Regression Discontinuity plot with quadratic time trend for end of 2005 NBP season (constant shift only). The dependent variable is total average daily NO_x emissions (in 1000's of Tons) in the NBP participating states in September and October, 2005. The fitted RDD lines use a quadratic time trend, with shared time trend parameters on either side of the discontinuity – only the regression intercept term differs on either side.

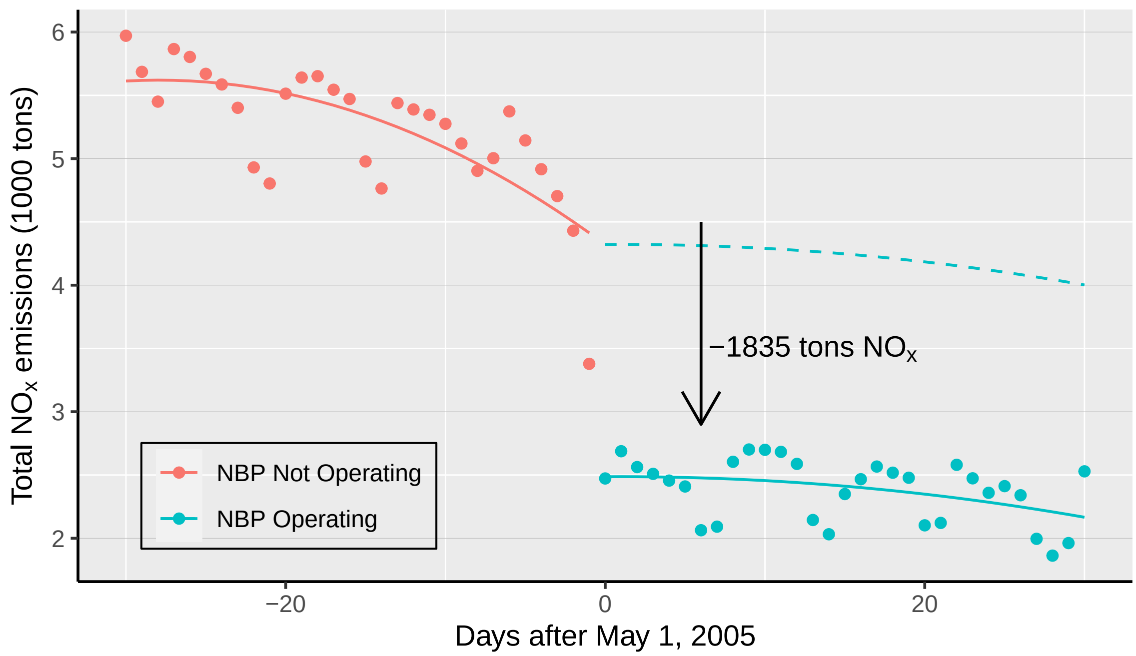

Figure 4: Regression Discontinuity plot with quadratic time trend for beginning of 2005 NBP season (constant and trend shifts). The dependent variable is total average daily NO_x emissions (in 1000's of Tons) in the NBP participating states in September and October, 2005. The fitted RDD lines use a quadratic time trend, with separate time trend parameters on either side of the discontinuity (a spline RDD) – both the intercept and time trend parameters differs on either side of the regulation threshold (October 1st).

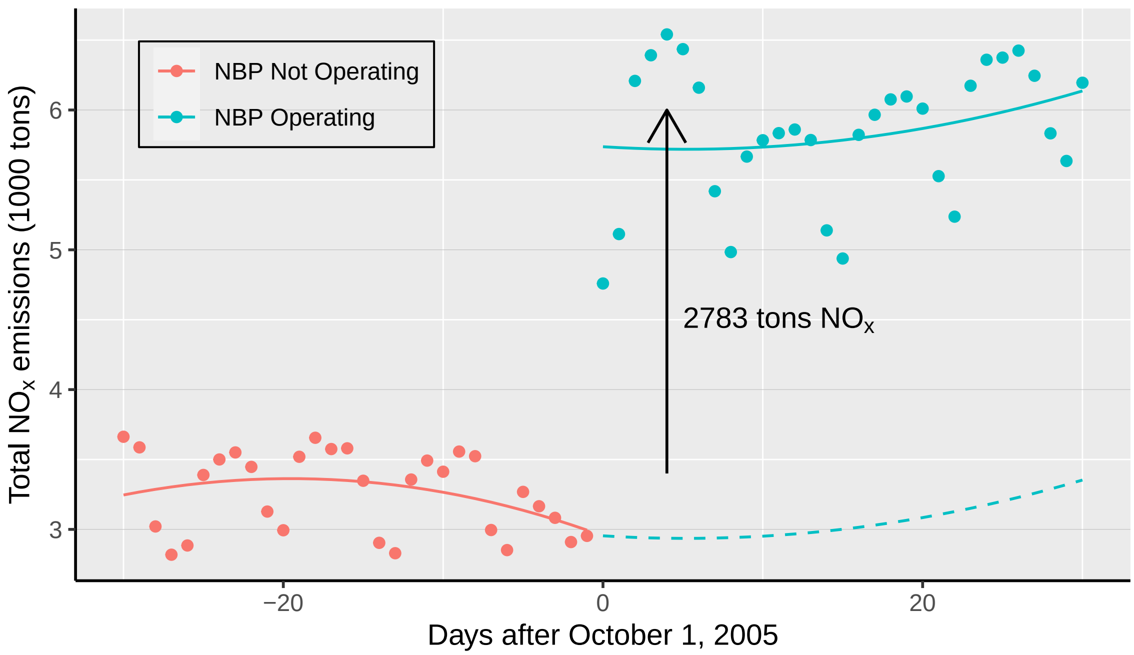

Figure 5: Regression Discontinuity plot with quadratic time trend for beginning of 2005 NBP season (constant shift only). The dependent variable is total average daily NO_x emissions (in 1000's of Tons) in the NBP participating states in April and May, 2005. The fitted RDD lines use a quadratic time trend, with shared time trend parameters on either side of the discontinuity – only the regression intercept term differs on either side.

Table 2: NBP Cross-sectional, Seasonal Mean Results for 2005

	Season-Mean Daily Emissions per state (tons)
	Season level Cross Section
Ozone Season Indicator	-1.644^{**}
	(0.672)
Observations	40
Adjusted R^2	0.113
Note:	*p<0.1; **p<0.05; ***p<0.01

Notes: The season-mean NO_x emissions in Table 2 are average daily NO_x emissions at the state level, averaged over all the days in the ozone season (compared to the mean over the the days outside the ozone season).

Table 3: NBP Differences Regression Results

	Total Region Daily Emissions (1000 tons)		
	Pre-Post Diff-in-Diff	East-West Diff-in-Diff	Triple Differences
NBP Participation	-2.888^{***}	-3.323^{***}	-2.687^{***}
	(0.110)	(0.090)	(0.126)
East only	Yes	No	No
2005 only	No	Yes	No
Observations	730	730	1,460
Adjusted R^2	0.774	0.767	0.750

Note: *p<0.1; **p<0.05; ***p<0.01
Region-total daily NO_xemissions are the sum of total average daily NO_xemissions of all states in each region.

Table 4: NBP Differences Regression Results

	Total Region Daily Emissions (1000 tons)		
	Pre-Post Diff-in-Diff	East-West Diff-in-Diff	Triple Differences
NBP Participation	-2.888^{***}	-3.323^{***}	-2.687^{***}
	(0.110)	(0.090)	(0.126)
year = 2005	-0.410^{***}		-0.599^{***}
	(0.071)		(0.058)
East Region		1.463^{***}	1.273^{***}
		(0.058)	(0.058)
Ozone Season (May-Sept)	-0.209^{***}	0.225^{***}	0.427^{***}
	(0.077)	(0.063)	(0.063)
year=2005 & Ozone Season			-0.202^{**}
			(0.089)
year=2005 & East Region			0.189^{**}
			(0.082)
Ozone Season & East Region			-0.636^{***}
			(0.089)
Intercept	6.720^{***}	4.848^{***}	5.447^{***}
	(0.050)	(0.041)	(0.041)
East only	Yes	No	No
2005 only	No	Yes	No
Observations	730	730	1,460
Adjusted R^2	0.774	0.767	0.750

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Region-total daily NO_xemissions are the sum of total average daily NO_xemissions of all states in each region.

15 Code

```
## ----setup, include=FALSE------------------------------------------------------------
knitr::opts_chunk$set(echo = TRUE)


## ----Settings, echo=FALSE---------------------------------------------------------
# stargazer table type (html, latex, or text)
# Change to latex when outputting to PDF, html when outputting to html
table_type = "latex"
cache_chunks = T
fig_h = 3.5
fig_w = 6


## ----packages, include=F, eval=T-------------------------------------------------
library(tidyverse)
library(haven)
library(fs)  # file handling
library(Hmisc)  # adding labels to data
library(latex2exp)  # latex in strings
library(stargazer)  # tables
library(rddtools)  # Regression discontinuity

plot_theme1 = theme(legend.title = element_blank(),
                    legend.box.margin = margin(-0.3, 0, -0.1, 0, "cm"),
                    legend.background = element_blank(),
                    legend.box.background = element_rect(colour = "black"),
                    panel.grid.major.x = element_blank(),
                    panel.grid.major.y = element_line( size=.1, color="grey" ),
                    axis.line.x = element_line(size=0.5, color='black'),
                    axis.line.y = element_line(size=0.5, color='black'),
                    plot.background = element_blank())


## ----Load Data, results='hide', echo=F, warning=F, message=F, cache=cache_chunks----
# Data labels
variable_labels_df = read.csv('datadefinitions.csv')
variable_labels <- setNames(as.character(variable_labels_df$Definition), variable_labels
# Participating states
states_df = read_csv('nbp_states.csv', show_col_types=F) %>%
    left_join(., read_csv('state_abbr_lookup.csv', show_col_types=F), by = c('state' = '
# load data
data = bind_rows(lapply(dir_ls('./data/', recurse=T, regexp='emission_(.)*(.csv)'), read
```

```r
    Hmisc::upData(., labels = variable_labels) %>%
    mutate(nbp = ifelse(State %in% states_df$Postal, 1, 0))  # NBP participating states


## ----Create Variables, include=F, cache=cache_chunks-----------------------------------
df = data %>%
    select(State, 'Facility ID (ORISPL)', Date, Year, 'NOx (tons)', County, 'Operating T
    rename(state=State, id='Facility ID (ORISPL)', date=Date, year=Year, nox='NOx (tons)
    mutate(day_of_year = lubridate::yday(date),
           day_of_week = lubridate::wday(date, label=T, week_start=3),  # reference cate
           month = lubridate::month(date),
           nox = ifelse(operating_time==0 & is.na(nox), 0, nox)) %>%
    filter(!is.na(nox))


## ----total daily mean nox, include=F, cache=cache_chunks-----------------------------
# OLS regression of NOx emissions on six day-of-week indicators and a constant
# reference category = Wednesday
reg_fig1 = lm(nox ~ day_of_week, data=df %>% filter(nbp == 1))
# nox_hat = constant plus the regression residuals
df_daily_sums = df %>%
    filter(nbp == 1) %>%  # filter in only NBP participating states
    mutate(nox_hat = reg_fig1$coefficients['(Intercept)'] + reg_fig1$residuals) %>%
    group_by(day_of_year, year) %>%
    summarise(nox_daily_sum = sum(nox_hat, na.rm=T)/1000)


## ----data: 2005 aggregation, echo=F, results='hide'----------------------------------
df_2005_agg = df %>%
    filter(year == 2005, nbp == 1) %>%
    group_by(day_of_year) %>%
    summarise(nox_daily_sum = sum(nox, na.rm=T)/1000,
              year = mean(year), month=mean(month)) %>%
    mutate(ozone_season = if_else(day_of_year %in% lubridate::yday('2005-05-01'):lubrida
    Hmisc::upData(., labels = list(nox_daily_sum = "Sum of daily avg NOx emissions from


## ----May regression constant only, echo=F-----------------------------------------------
reg_poly1 = df_2005_agg %>%
    filter(month %in% c(4,5)) %>%
    rdd_data(nox_daily_sum, day_of_year, data=.,
             cutpoint=lubridate::yday('2005-05-01')) %>%
    rdd_reg_lm(slope = "same", order = 2)
```

```
poly1_coef = reg_poly1$coefficients[2]


## ----Sept regression constant only, echo=F---------------------------------------------
reg_poly2 = df_2005_agg %>%
    filter(month %in% c(9,10)) %>%
    rdd_data(nox_daily_sum, day_of_year, data=.,
             cutpoint=lubridate::yday('2005-10-01')) %>%
    rdd_reg_lm(slope = "same", order = 2)

poly2_coef = reg_poly2$coefficients[2]


## ----May regression separate trends, echo=F--------------------------------------------
reg_poly3 = df_2005_agg %>%
    filter(month %in% c(4,5)) %>%
    rdd_data(nox_daily_sum, day_of_year, data=.,
             cutpoint=lubridate::yday('2005-05-01')) %>%
    rdd_reg_lm(slope = "separate", order = 2)

poly3_coef = reg_poly3$coefficients[2]


## ----Sept regression separate trends, echo=F-------------------------------------------
reg_poly4 = df_2005_agg %>%
    filter(month %in% c(9,10)) %>%
    rdd_data(nox_daily_sum, day_of_year, data=.,
             cutpoint=lubridate::yday('2005-10-01')) %>%
    rdd_reg_lm(slope = "separate", order = 2)

poly4_coef = reg_poly4$coefficients[2]


## ----data: season means, include=F-----------------------------------------------------
df_ozone_season_mean = df %>%
    filter(year == 2005, nbp == 1) %>%
    mutate(ozone_season = if_else(day_of_year %in% lubridate::yday('2005-05-01'):lubrida
    group_by(state, ozone_season) %>%
    summarise(nox_dm_season = mean(nox, na.rm=T)) %>%
    Hmisc::upData(., labels = list(nox_dm_season = "Mean total daily NOx emissions from


## ----cross sectional season means regression, echo=F----------------------------------
reg_cross = df_ozone_season_mean %>%
```

```
    lm(nox_dm_season ~ ozone_season, data=.)

cross_coef = reg_cross$coefficients[2]


## ----data: pre-post-means, include=F-----------------------------------------
df_diff = df %>%
    group_by(day_of_year, year, nbp) %>%
    summarise(nox_dm_region = sum(nox, na.rm=T)/1000) %>%
    Hmisc::upData(., labels = list(nox_dm_region = "total daily NOx emissions from NBP s
    mutate(ozone_season = if_else(day_of_year %in% lubridate::yday('2005-05-01'):lubrida
           treat = ozone_season*(year==2005)*nbp)


## ----pre-post diffndiff regression, echo=F-----------------------------------
reg_pre_post = df_diff %>%
    filter(nbp == 1) %>%
    lm(nox_dm_region ~ factor(year) + ozone_season + treat, data=.)

pre_post_coef = reg_pre_post$coefficients[4]
summary(reg_pre_post)
summary(reg_pre_post, cluster="year")


## ----east diffndiff regression, echo=F----------------------------------------
reg_east_west = df_diff %>%
    filter(year == 2005) %>%
    lm(nox_dm_region ~ nbp + ozone_season + treat, data=.)
# nbp = 1 if east

east_west_coef = reg_east_west$coefficients[4]


## ----triple diffndiff regression, echo=F--------------------------------------
reg_triple_diff = df_diff %>%
    lm(nox_dm_region ~ factor(year) + ozone_season + nbp
       + factor(year)*ozone_season + factor(year)*nbp + ozone_season*nbp
       + treat, data=.)
# nbp = 1 if east

triple_diff_coef = reg_triple_diff$coefficients[5]


## ----Figure1, echo=F, message=F, fig.height=4, fig.width=7,  fig.cap="Total Daily no
```

```
ggplot(df_daily_sums, aes(x=day_of_year, y=nox_daily_sum, group=year)) +
    geom_line(aes(linetype=factor(year)), color='darkblue') +
    ggtitle(TeX('')) +
    ylab('') +
    scale_x_continuous('Day of year',
                       breaks=lubridate::yday(c('2002-01-01', '2002-05-01', '2002-10-01'
                       labels=c('Jan 1', 'May 1', 'Oct 1', 'Dec 31'),
                       limits=c(1,365), expand=c(0.02,0.02)) +
    scale_y_continuous(expand=c(0.05,0.05),
                       breaks=c(2,4,6,8)) +
    plot_theme1 + theme(legend.position = c(0.9, 0.2)) +
    scale_linetype_manual(name = "Linetype",
                          values = c('2005'=1, '2002'=2))


## ----polynomial-regs, results='asis', echo=F, eval=T-------------------------------
stargazer(reg_poly1, reg_poly2, reg_poly3, reg_poly4,
          title="NBP Polynomial Regression Discontinuity Results for 2005", align=TRUE,
          header=F, type=table_type,
          dep.var.caption = "Total Daily Emissions (1000 tons)",
          dep.var.labels = "",
          column.labels=c("\\shortstack{NBP Start \\\\ (May)}",
                          "\\shortstack{NBP End \\\\ (Sepember)}",
                          "\\shortstack{NBP Start \\\\ (May)}",
                          "\\shortstack{NBP End \\\\ (Sepember)}"),
          add.lines = list(c("Separate Time Trend?", "\\centering\\text{No}", "\\text{No
          covariate.labels = 'Ozone Season Indicator',
          keep='D',
          label = "tab:polynomial-regs",
          omit.stat = c("f", "rsq", "ser"), model.numbers=F
)


## ----RDD-poly-1-text, echo=F-------------------------------------------------------
text1 = "Regression Discontinuity plot with quadratic time trend for beginning
of 2005 NBP season (constant shift only). The dependent variable is total average daily
1000's of Tons) in the NBP participating states in April and May, 2005. The fitted
RDD lines use a quadratic time trend, with shared time trend parameters on either
side of the discontinuity -- only the regression intercept term differs on either side."
x_ = 1


## ----RDD-poly-1, echo=F, warning=F, message=F, fig.height = fig_h, fig.width = fig_w
data.frame(x = reg_poly1$model$x, y = reg_poly1$model$y, y_hat = reg_poly1$fitted.values
```

```r
    mutate(treat = as.factor(ifelse(x >= 0, 'NBP Operating', 'NBP Not Operating'))) %>%
    mutate(y_hat_shift = ifelse(treat=='NBP Operating', y_hat - poly1_coef, NA)) %>%
    ggplot(aes(x=x, y=y, color=treat)) + geom_point() +
    geom_line(aes(x=x, y=y_hat, color=treat)) +
    geom_line(aes(x=x, y=y_hat_shift), linetype = "dashed") +
    xlab('Days after May 1, 2005') +
    ylab(TeX('Total NO$_{x}$ emissions (1000 tons)')) +
    plot_theme1 + theme(legend.position = c(0.2, 0.15)) +
    annotate("segment", x = 3, y = 4.75, xend = 3, yend = 3,
                  arrow = arrow(length = unit(0.5, "cm"))) +
    annotate("text", x = 10+x_, y = 3.75, label = TeX(paste(round(poly1_coef,3)*1000, "t


## ----RDD-poly-2-text, echo=F------------------------------------------------------
text2 = "Regression Discontinuity plot with quadratic time trend for end of 2005
NBP season (constant shift only). The dependent variable is total average daily \\nox em
1000's of Tons) in the NBP participating states in September and October, 2005. The fitt
RDD lines use a quadratic time trend, with shared time trend parameters on either
side of the discontinuity -- only the regression intercept term differs on either side."


## ----RDD-poly-2, echo=F, warning=F, message=F, fig.height = fig_h, fig.width = fig_w
data.frame(x = reg_poly2$model$x, y = reg_poly2$model$y, y_hat = reg_poly2$fitted.values
    mutate(treat = as.factor(ifelse(x >= 0, 'NBP Operating', 'NBP Not Operating'))) %>%
    mutate(y_hat_shift = ifelse(treat=='NBP Operating', y_hat - poly2_coef, NA)) %>%
    ggplot(aes(x=x, y=y, color=treat)) + geom_point() +
    geom_line(aes(x=x, y=y_hat, color=treat)) +
    geom_line(aes(x=x, y=y_hat_shift), linetype = "dashed") +
    xlab('Days after October 1, 2005') +
    ylab(TeX('Total NO$_{x}$ emissions (1000 tons)')) +
    plot_theme1 + theme(legend.position = c(0.2, 0.85)) +
    annotate("segment", x = 4, y = 3.7, xend = 4, yend =5.9,
                  arrow = arrow(length = unit(0.5, "cm"))) +
    annotate("text", x = 10+x_, y = 4.5, label = TeX(paste(round(poly2_coef,3)*1000, "to


## ----RDD-poly-3-text, echo=F------------------------------------------------------
text3 = "Regression Discontinuity plot with quadratic time trend for beginning of
2005 NBP season (constant and trend shifts). The dependent variable is total average dai
1000's of Tons) in the NBP participating states in September and October, 2005. The fitt
RDD lines use a quadratic time trend, with separate time trend parameters on either
side of the discontinuity (a spline RDD) -- both the intercept and time trend
parameters differs on either side of the regulation threshold (October 1st)."
```

```r
## ----RDD-poly-3, echo=F, warning=F, message=F, fig.height = fig_h, fig.width = fig_w
data.frame(x = reg_poly3$model$x, y = reg_poly3$model$y, y_hat = reg_poly3$fitted.values
    mutate(treat = as.factor(ifelse(x >= 0, 'NBP Operating', 'NBP Not Operating'))) %>%
    mutate(y_hat_shift = ifelse(treat=='NBP Operating', y_hat - poly3_coef, NA)) %>%
    ggplot(aes(x=x, y=y, color=treat)) + geom_point() +
    geom_line(aes(x=x, y=y_hat, color=treat)) +
    geom_line(aes(x=x, y=y_hat_shift), linetype = "dashed") +
    xlab('Days after May 1, 2005') +
    ylab(TeX('Total NO$_{x}$ emissions (1000 tons)')) +
    plot_theme1 + theme(legend.position = c(0.2, 0.15)) +
    annotate("segment", x = 6, y = 4.5, xend = 6, yend = 2.9,
              arrow = arrow(length = unit(0.5, "cm"))) +
    annotate("text", x = 12+x_, y = 3.5, label = TeX(paste(round(poly3_coef,3)*1000, "to


## ----RDD-poly-4-text, echo=F---------------------------------------------------------
text4 = "Regression Discontinuity plot with quadratic time trend for end of 2005
NBP season (constant and trend shifts). The dependent variable is total average daily \\
1000's of Tons) in the NBP participating states in September and October, 2005.
The fitted RDD lines use a quadratic time trend, with separate time trend parameters on
side of the discontinuity (a spline RDD) -- both the intercept and time trend
parameters differs on either side of the regulation threshold (October 1st)."


## ----RDD-poly-4, echo=F, warning=F, message=F, fig.height = fig_h, fig.width = fig_w
data.frame(x = reg_poly4$model$x, y = reg_poly4$model$y, y_hat = reg_poly4$fitted.values
    mutate(treat = as.factor(ifelse(x >= 0, 'NBP Operating', 'NBP Not Operating'))) %>%
    mutate(y_hat_shift = ifelse(treat=='NBP Operating', y_hat - poly4_coef, NA)) %>%
    ggplot(aes(x=x, y=y, color=treat)) + geom_point() +
    geom_line(aes(x=x, y=y_hat, color=treat)) +
    geom_line(aes(x=x, y=y_hat_shift), linetype = "dashed") +
    xlab('Days after October 1, 2005') +
    ylab(TeX('Total NO$_{x}$ emissions (1000 tons)')) +
    plot_theme1 + theme(legend.position = c(0.2, 0.85)) +
    annotate("segment", x = 4, y = 3.4, xend = 4, yend = 6,
              arrow = arrow(length = unit(0.5, "cm"))) +
    annotate("text", x = 10+x_, y = 4.5, label = TeX(paste(round(poly4_coef,3)*1000, "to


## ----cross-sectional-reg, results='asis', echo=F, eval=T----------------------------
stargazer(reg_cross,
          title="NBP Cross-sectional, Seasonal Mean Results for 2005", align=TRUE,
          header=F, type=table_type,
          dep.var.caption = "Season-Mean Daily Emissions per state (tons)",
```

```
          dep.var.labels = "",
          column.labels=c("\\shortstack{Season level \\\\ Cross Section}"),
          covariate.labels = 'Ozone Season Indicator',
          keep='ozone_season',
          label = "tab:cross-sectional-reg",
          omit.stat = c("f", "rsq", "ser"), model.numbers=F
)


## ----diff-regs-short, results='asis', echo=F, eval=T--------------------------------
stargazer(reg_pre_post, reg_east_west, reg_triple_diff,
          title="NBP Differences Regression Results", align=TRUE,
          header=F, type=table_type,
          dep.var.caption = "Total Region Daily Emissions (1000 tons)",
          dep.var.labels = "",
          column.labels=c("\\shortstack{Pre-Post \\\\ Diff-in-Diff}",
                          "\\shortstack{East-West \\\\ Diff-in-Diff}",
                          "\\shortstack{Triple \\\\ Differences}"),
          covariate.labels = c('NBP Participation'),
          keep='treat',
          add.lines = list(c("East only", "\\centering\\text{Yes}", "\\text{No}", "\\tex
                           c("2005 only", "\\centering\\text{No}", "\\text{Yes}", "\\tex
          label = "tab:diff-regs-short",
          omit.stat = c("f", "rsq", "ser"), model.numbers=F,
          notes = c("Region-total daily \\nox  emissions are the sum of total average",
          "daily \\nox  emissions of all states in each region.")
)


## ----diff-regs-long, results='asis', echo=F, eval=T---------------------------------
stargazer(reg_pre_post, reg_east_west, reg_triple_diff,
          title="NBP Differences Regression Results", align=TRUE,
          header=F, type=table_type,
          dep.var.caption = "Total Region Daily Emissions (1000 tons)",
          dep.var.labels = "",
          column.labels=c("\\shortstack{Pre-Post \\\\ Diff-in-Diff}",
                          "\\shortstack{East-West \\\\ Diff-in-Diff}",
                          "\\shortstack{Triple \\\\ Differences}"),
          order = c('treat'),
          covariate.labels = c('NBP Participation',
                               'year = 2005',
                               'East Region',
                               'Ozone Season (May-Sept)',
                               'year=2005 \\& Ozone Season',
```

```
                                'year=2005 \\& East Region',
                                'Ozone Season \\& East Region',
                                'Intercept'),
          add.lines = list(c("East only", "\\centering\\text{Yes}", "\\text{No}", "\\tex
                           c("2005 only", "\\centering\\text{No}", "\\text{Yes}", "\\tex
          label = "tab:diff-regs-long",
          omit.stat = c("f", "rsq", "ser"), model.numbers=F,
          notes = c("Region-total daily \\nox  emissions are the sum of total average",
          "daily \\nox  emissions of all states in each region.")
)


## ----eval=F---------------------------------------------------------------------
##
```

16 References

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17 Authorship Info

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