Environmental/Energy Economics
Lecture 2: Health Demand

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Health: Overview

- Health an important channel of environmental benefits
  - Air, water, climate, noise pollution
- How translate to welfare?
  - Inputs v. outputs?
  - Market power, moral hazard, adverse selection, dynamics, etc.?
- Grossman model landmark: health as human capital

Health: Overview

- Much economic research on health is health **care** (insurance, market design, etc.)
- Much environmental research involves health outcomes (mortality, morbidity)
  - Syllabus has some examples, there are many others
- Focus on one paper with alternative focus

Defensive Investments and the Demand for Air Quality: Evidence from the NOx Budget Program

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Motivation:

- Most studies of health impact of environmental regulations ignore economic costs associated defensive behavior

- People take costly actions to defend against risk or damage:
  - AC / energy consumption as protection against extreme heat
  - ** Medications to protect against from respiratory problems in response to changes in air quality**

- Looking at health outcomes alone understates the health costs of air pollution. Full adaptation => no health impacts

- Medications likely to be an important measure of defensive expenditures
  - Annual cost of medications for asthma >> the monetized value of any other component of asthma's social cost, including mortality, hospital admissions, or lost productivity (Weiss and Sullivan 2001)

Motivation (ctd):

- Emission markets now commonplace (EU-ETS, California AB32, RGGI, etc), yet there are no comprehensive empirical evaluation of the health benefits associated with emission markets using ex-post real-world data
  - Prior evaluations of emission markets typically rely on ‘data’ predicted by chemistry, engineering, and epidemiological models
  - Absence of empirical analysis surprising since emission markets often motivated by benefits on health

- No study to date reports IV estimates of the effect of NOx emission on health outcomes and defensive investments
  - Key component of debate about regulation of NOx emissions as a means to reduce ambient ozone concentrations
  - Fall 2015: VW & new CAA standard on ozone

This Paper:

- Study NO_x (nitrogen oxide) Budget Trading Program (NBP), an emission market
  - 2003-2008, Midwest & Eastern US, May 1st – September 30th
  - Evolved into CAIR and now CSAPR

- Impact of emissions market on:
  - Emitted pollution at facility level
  - Ambient pollution
  - Medication purchases (>>100 million transactions)
  - Hospital visits
  - Mortality rates

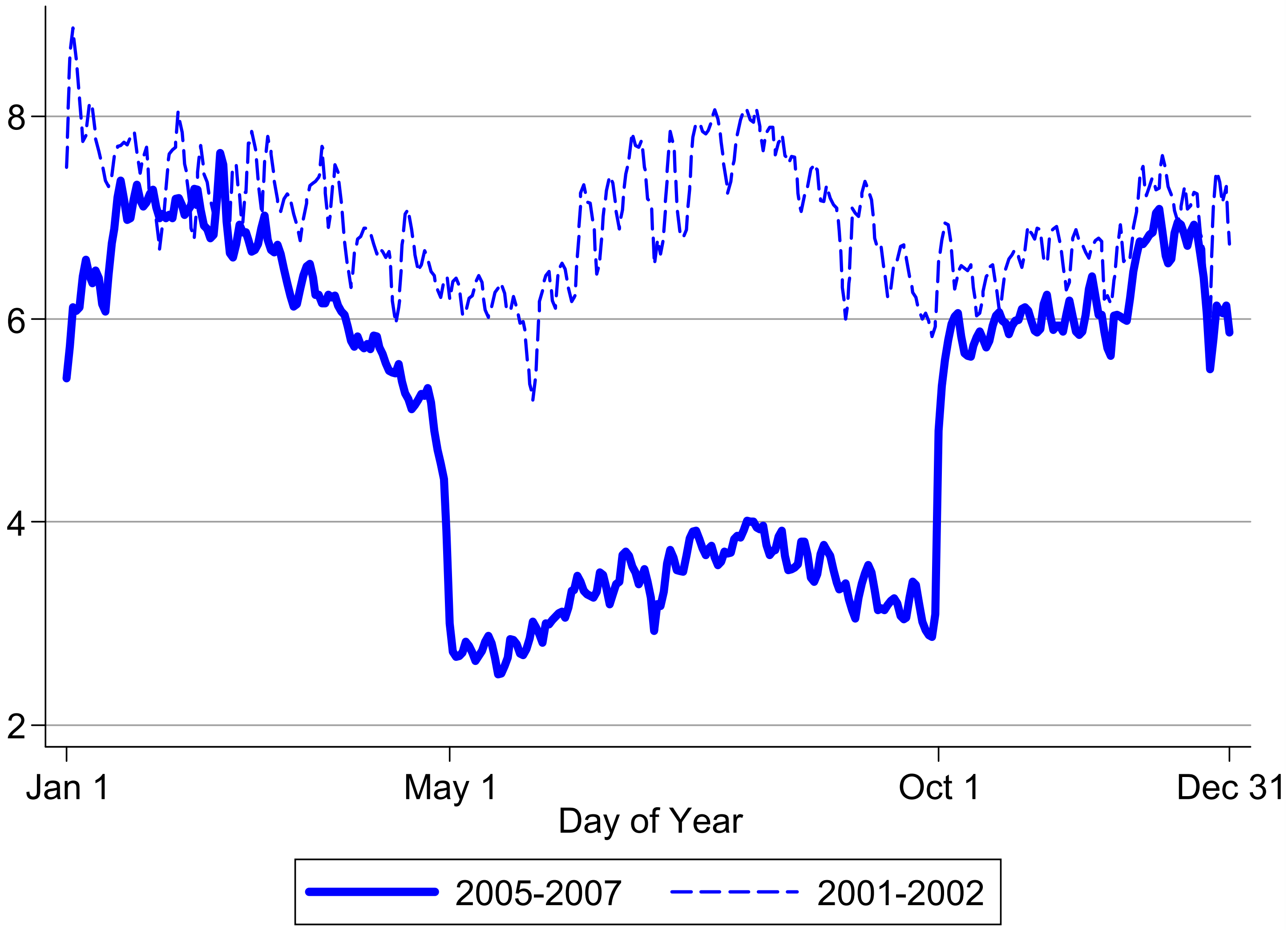
- Based on this, we develop a measure of willingness to pay for air quality improvements that accounts for both the direct health impacts and defensive investments

Approach:

- Rely on variation generated by the implementation of the NBP emission market
  - Leads way to reduced-form DDD estimation and event-study graphs
  - IV estimation of the effect of NOx on health outcomes and defensive investments
  - IV estimation of effect of ozone, although the identification strategy in that case is not quite as clear cut. Some caution required in interpretation of ozone IV estimates

NBP's Aggregate Impact on NO_x Emissions

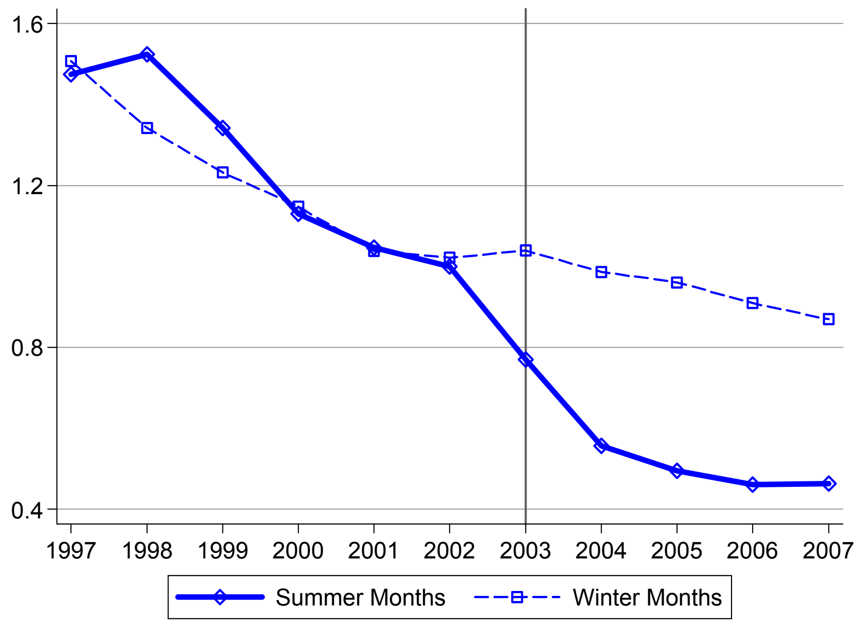
[Emissions in Thousand Tons]



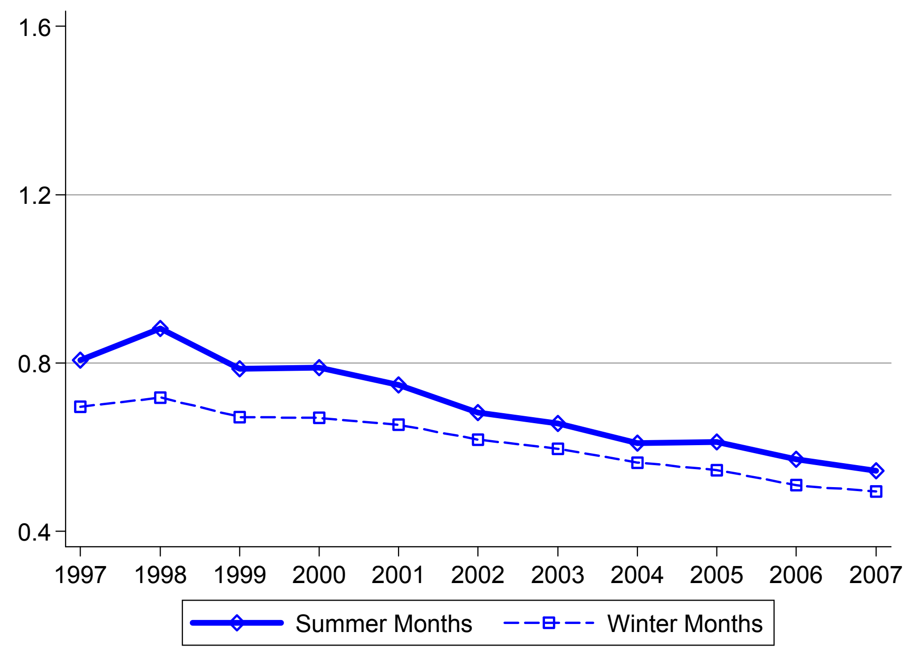
Note: Graph depicts fitted NO_x residuals after partialing day-of-week indicators.

NBP's Seasonal and Regional Impacts on NO_x Emissions

NBP States



Non-NBP States



Note: Y-axis shows summer-equivalent NOx emissions (Mil. Tons)

Main Results 1:

- NO_x Budget Trading Program decreased NO_x emissions by about 35%
- NOx is a primary ingredient in the complex function that produces ozone:
  - $\Rightarrow$ Reductions in summer ozone concentrations of 6%
  - $\Rightarrow$ Reduced the number of summer days with high ozone levels (>65 ppb) by 10 ($\sim$ 40% reduction)

Main Results 2:

- Improved air quality due to NBP generate large benefits:
  - 1.5% Reduction in medication purchases: saved $800 million in defensive investments annually
    - Evident in short-acting and long-term control respiratory medications
    - Almost as large as abatement costs associated with NBP
  - 0.5% Reduction in mortality rate -- prevented 2,500 summertime deaths each year, primarily age 75+ population
    - Monetized value of reduction in mortality (age-adjusted VSL) ≈ $1500 million
    - Models that consider longer displacement windows yield similar results, but are less precise
  - Cannot detect effect on hospital visits (ER) expenditures

Main Results 3:

- Paper provides the first IV estimates of the effect of NOx emissions on health and defensive investments
  - Important for air quality policymaking since NOx is a pollutant that can be controlled directly by regulation (and ozone cannot)

  - Estimates suggest that there is a causal link between NOx emissions, medication purchases, and mortality
    - Especially in urban / more populated counties
    - 10% reduction in NOx emissions: $\Rightarrow$ 0.1% reduction in medication purchases and in mortality

  - We cautiously interpret these effects as caused by ozone concentration reductions driven by the NBP's NOx reductions *(since NO_x can undergo reactions to become PM and SO_2)*

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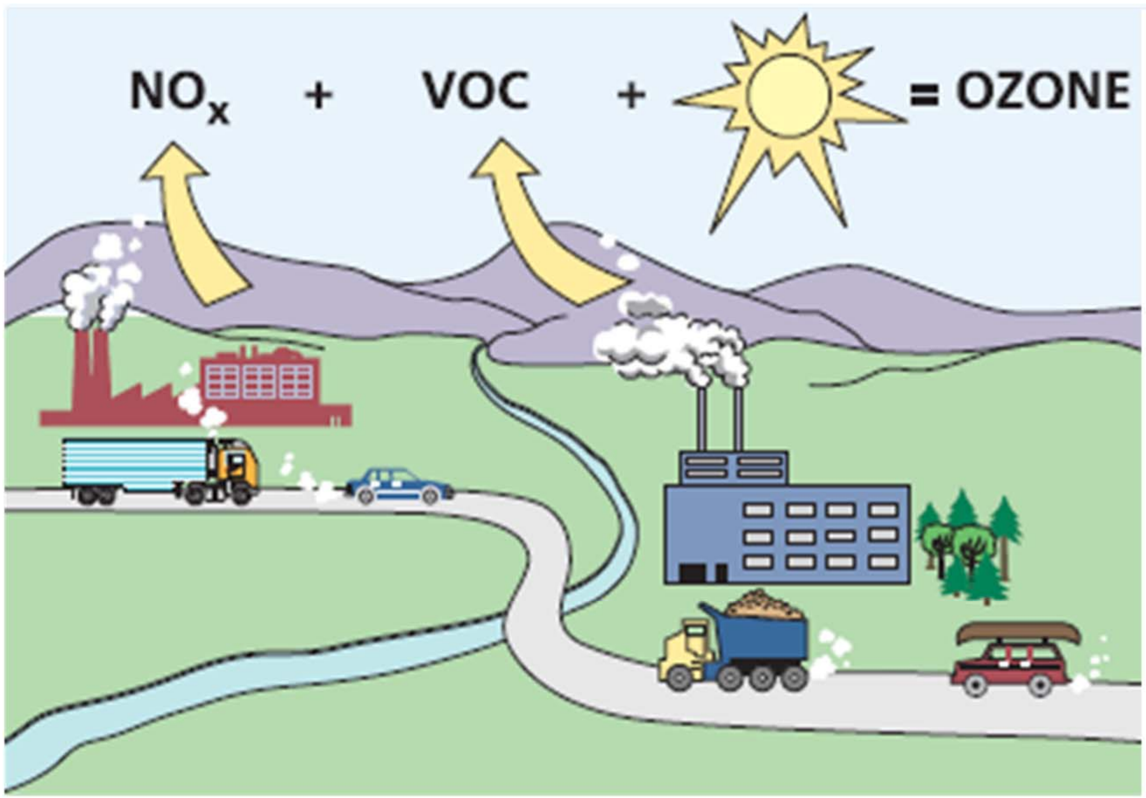
Ozone Formation is Complex & Ozone Not Directly Controllable

- Ozone = NO_x + VOC + Heat
- VOC=Volatile Organic Compounds

  (benzene, formaldehyde, …)



$O(^1D) + H_2O \rightarrow 2OH$		2.2×10^{-10}
$O(^1D) + CH_4 \xrightarrow{O_2} CH_3O_2 + OH$		1.4×10^{-10}
$OH + CH_4 \xrightarrow{O_2} CH_3O_2 + H_2O$		$2.4 \times 10^{-12} \exp(-1710/T)$
$O(^1D) + H_2 \xrightarrow{O_2} HO_2 + OH$		1.0×10^{-10}
$OH + H_2 \xrightarrow{O_2} HO_2 + H_2O$		$6.1 \times 10^{-12} \exp(-2030/T)$
$OH + CO \xrightarrow{O_2} HO_2 + CO_2$		$1.5 \times 10^{-13} (1. + 0.6\ p(\mathrm{atm}))$
$OH + HO_2 \rightarrow H_2O + O_2$		$(7 + 4\ p(\mathrm{atm}))\ 10^{-11}$
$OH + O_3 \rightarrow HO_2 + O_2$		$1.6 \times 10^{-12} \exp(-940/T)$
$HO_2 + O_3 \rightarrow OH + 2O_2$		$1.4 \times 10^{-14} \exp(-580/T)$
$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$		$[1.9 \times 10^{-33} M \exp(980/T) + 2.2 \times 10^{-13} \exp(620/T)] (1 + 1.4 \times 10^{-21} \exp(2200/T) H_2O)^a$
$OH + H_2O_2 \rightarrow HO_2 + H_2O$		$3.1 \times 10^{-12} \exp(-187/T)$
$HO_2 + NO \rightarrow NO_2 + OH$		$3.7 \times 10^{-12} \exp(240/T)$
$NO + O_3 \rightarrow NO_2 + O_2$		$1.8 \times 10^{-12} \exp(-1370/T)$
$OH + HNO_3 \rightarrow H_2O + NO_3$		$9.4 \times 10^{-15} \exp(778/T)$
$NO_3 + NO \rightarrow 2NO_2$		2×10^{-11}
$NO_2 + O_3 \rightarrow NO_3 + O_2$		$1.2 \times 10^{-13} \exp(-2450/T)$
$CH_3O_2 + HO_2 \rightarrow CH_3OOH + O_2$		$7.7 \times 10^{-14} \exp(1300/T)$
$CH_3O_2 + CH_3O_2 \rightarrow 2HO_2 + 2CH_2O$	(a)	$K = 1.6 \times 10^{-13} \exp(220/T)$
$\rightarrow CH_2O + CH_3OH$	(b)	$K_a = 0.38\ K, K_b = 0.62\ K$
$CH_3OOH + OH \rightarrow CH_3O_2 + H_2O$	(a)	$K = 1 \times 10^{-11}$
$\rightarrow CH_2O + OH + H_2O$	(b)	$K_a = 0.56\ K, K_b = 0.44\ K$
$CH_3O_2 + NO \xrightarrow{O_2} HO_2 + CH_2O + NO_2$		$4.2 \times 10^{-12} \exp(180/T)$
$CH_2O + OH \xrightarrow{O_2} HO_2 + H_2O + CO$		1×10^{-11}
$OH + NO \xrightarrow{O_2} HNO_2$		2×10^{-12}
$NO + NO_2 + H_2O \rightarrow 2HNO_2$		6×10^{-37}
$O(^1D) + M \rightarrow O(^3P)$		2.88×10^{-11}
$OH + HO_2NO_2 \rightarrow \text{products}$		$1.3 \times 10^{-12} \exp(380/T)$
$OH + C_2H_6 \xrightarrow{O_2} C_2H_5O_2$		$1.86 \times 10^{-11} \exp(-1231/T)$
$C_2H_5O_2 + NO \xrightarrow{O_2} CH_3CHO + NO_2 + HO_2$		$3.7 \times 10^{-12} \exp(240/T)$
$OH + C_3H_8 \xrightarrow{O_2} C_3H_7O_2$		$1.2 \times 10^{-11} \exp(-679/T)$
$C_3H_7O_2 + NO \xrightarrow{O_2} CH_3COCH_3 + NO_2 + HO_2$		$3.7 \times 10^{-12} \exp(240/T)$
$OH + C_2H_4 \xrightarrow{O_2} C_2H_4OHO_2$		$2.18 \times 10^{-12} \exp(387/T)$
$C_2H_4OHO_2 + NO \xrightarrow{O_2} 2CH_2O + NO_2 + HO_2$		$3.7 \times 10^{-12} \exp(240/T)$
$OH + C_3H_6 \xrightarrow{O_2} C_3H_6OHO_2$		$4.1 \times 10^{-12} \exp(544/T)$
$C_3H_6OHO_2 + NO \xrightarrow{O_2} CH_2O + CH_3CHO + NO_2 + HO_2$		$3.7 \times 10^{-12} \exp(240/T)$
$O_3 + C_2H_4 \rightarrow CH_2O + 0.4CH_2O_2 + 0.4\ CO + 0.1\ HO_2$		$2.57 \times 10^{-14} \exp(-2828/T)$

Ozone: Health Effects -> RD & CVD conditions

- 1. Association between <u>daily</u> ozone concentrations and <u>daily</u> mortality rates (Bell et al 2004; Schwartz et al. 2005)
  - EPA benefit-costs analysis driven by these results
- 2. Ozone not associated with infant mortality (Currie and Neidell 2005)
  - Controls for zip code fixed effects
- 3. Ozone is associated with hospitalizations (Moretti and Neidell 2011; Lleras-Muney 2010)
  - Boats in Los Angeles port / Army relocations
- 4. Smog alerts reduce outdoor activity (Neidell 2009)
  - Zoo and park attendance falls

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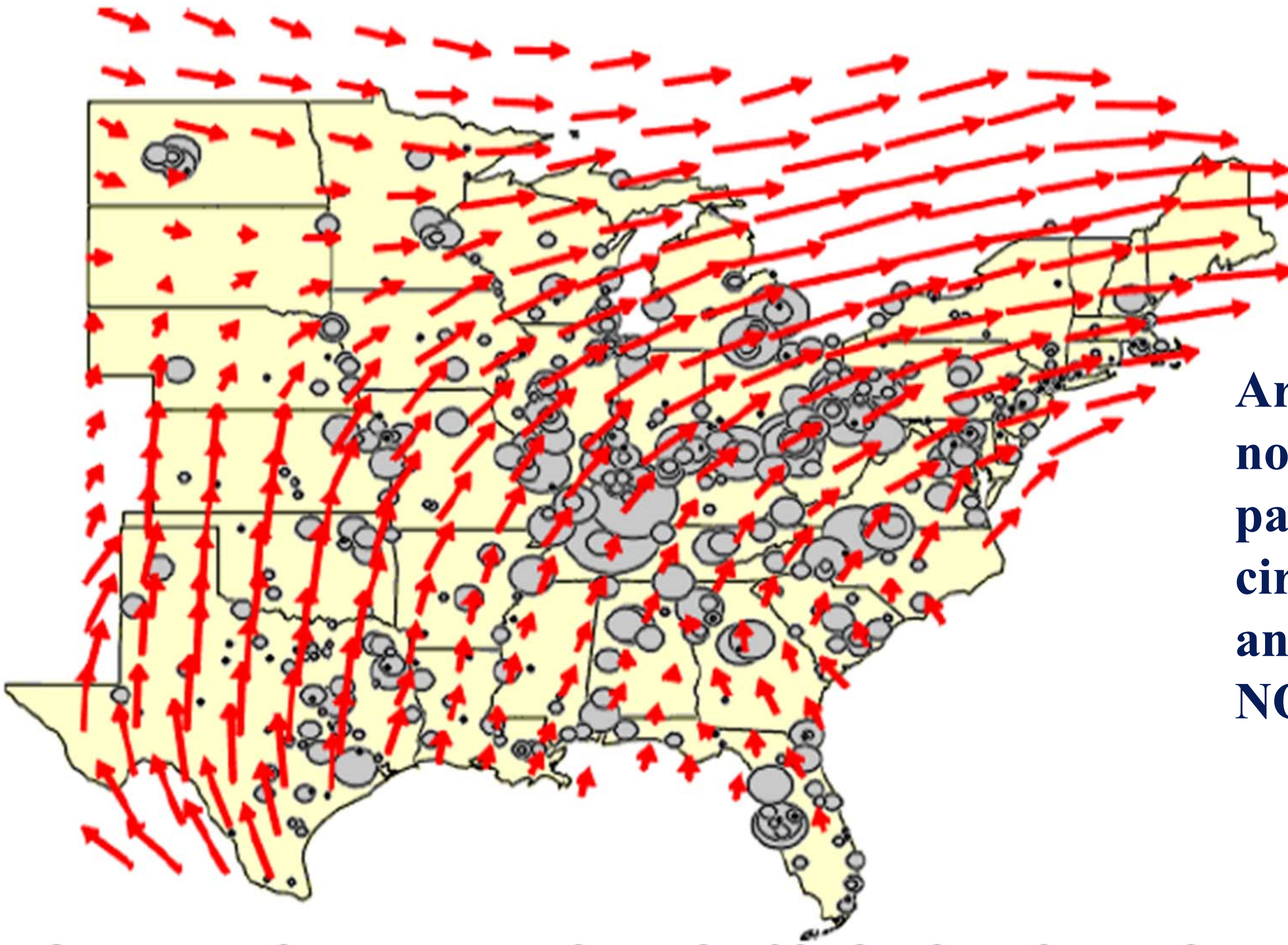
NOx/Ozone Regulation Timeline:

- NO_x cap-and-trade markets:
  - 1994-now: RECLAIM (California)
  - 1999-2002: Ozone Transport Commission market (New England)
  - 2003-2008: NO_x Budget Program (Eastern & Midwest US)
  - 2009-2014: CAIR (Eastern & Midwest US) – covers NO_x and SO_2 – effectively replaced NBP
  - 2015: Cross-State Air Pollution Rule now implemented

- Ozone not directly controlled. Clean Air Act and Ozone National Ambient Air Quality Standards
  - Violations lead to “non-attainment” designation and penalties for state, counties, and industries
  - Standard changes from 1971 – 2015
  - Current standard: 70 ppb 8-hour daily maximum (2015)

NO_x Budget Trading Program
(as a solution to ozone standard violations in Northeast)

- ~ 1990s: Many Eastern states (OTC) argued that they were unfairly subject to CAA Nonattainment Regulations for ozone due to NOx emissions from Midwestern states:

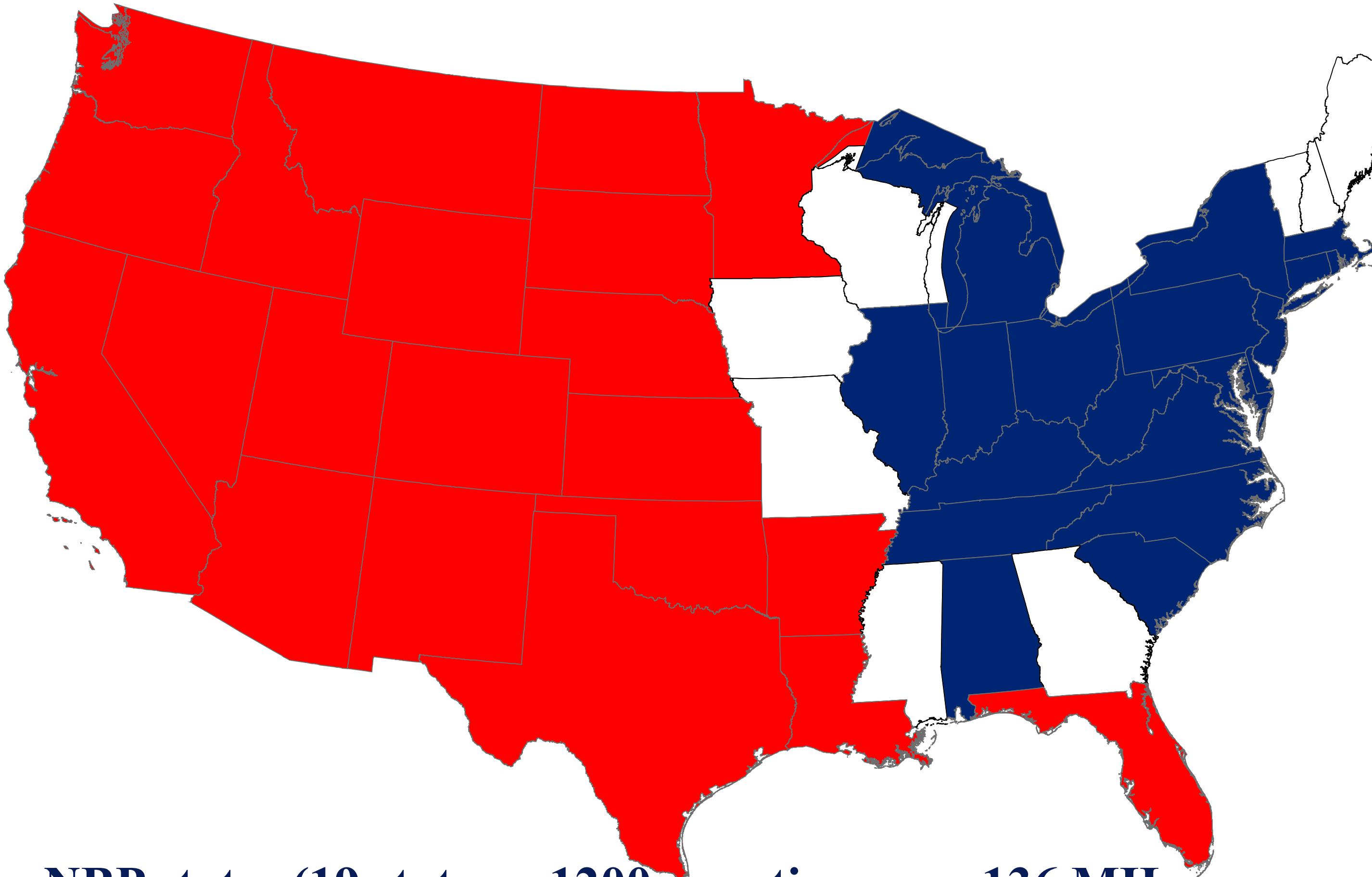


Arrows show normal wind patterns and circles are location and amount of NO_x emissions

NO_x Budget Trading Program: Details

- EPA set single cap for 19 states and gave option for command-and-control or cap-and-trade
- All opted for cap-and-trade: 8 states in 2003, 11 in 2004
- Operated May 1 – September 30, 2003-2008
- 2500+ point sources (electricity generation & industrial boilers). 700 coal power plants account for 95% of NOx in NBP
  - Overall shares of NO_x emissions: Utilities 21%, Other Industries 11%; Transportation 60%; Others 8%

NO_x Budget Trading Program: States



Blue: NBP states (19 states, ~1200 counties, pop=136 MIL

Red: Non-participating state (20 states, ~ 1300 counties, pop=125 MIL)

White: border states (excluded from analysis)

<u>Study sample</u>: Blue and Red states (2539 counties)

Rules of the NOx Budget Trading Program

- States allocate permits (NBP cap ~ 550,000 tons/year) to polluters
- Firms can buy and sell permits
  - Market price averaged ~$2500/ton of NOx ($2015)
  - Each Fall, firms give EPA one permit for each ton of NOx emitted during the preceding summer
  - Permits may be banked 1:1 across years
- 70% of units retrofit (e.g., SCR, CM, Low NO_x Burner)
- 30% used other compliance (e.g., buy permits, switch fuels)

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Model: Grossman (1972) health production function

- S = S(D,M) = measure of -health (ex: hours per week sick)
- D = D(C,A) = dose of air pollution ingested
- C = ambient air pollution (assumed exogenous)
- A = amount of <u>averting</u> activity chosen by individual to avoid exposure to pollution (i.e. stay indoors, buy air filters)
- M = amount of <u>mitigating</u> activity chosen by individual to reduce health effects of exposure of pollution (i.e. medications). No direct utility
- $\Rightarrow$ S=S(C,A,M). Ignore 'A' for rest

Consumer problem:

- $S = S(C,M) =$ "health production function"
- $U = U(X,L,S))$
- X = numeraire composite good
- L = leisure

- Budget constraint:
- $I + p_W(T - L - S) = X + p_M M$
  - [Time spent in sickness is lost (can't work, and does not count as leisure)]

- p_M = price of mitigating activity
- p_W = price of leisure (wage rate)

- $\Rightarrow$ Choose X, L, M to maximize U subject to budget constraint

Developing a measure of WTP

- Marginal willingness to pay (MWTP) for a small change in pollution defined as change in income needed to keep utility constant for a small change in pollution ingested

- In model this corresponds to the total derivative of the indirect utility function $v(I, p_W, p_M, C)$ with respect to C set at 0 (keep utility constant) and solving for dI/dC
  - *How can we express this in terms of variables we observe?*

- Harrington and Portney (1987) show that the MWTP can in principle be measured empirically if a valid estimate of the partial effect of air pollution on health is available (i.e. $\partial S/\partial C$)
  - *This is difficult to estimate since it requires holding constant all other health inputs ("A" and "M")*

Empirical Challenge:

- Most studies do not hold constant A and M, and so estimate the <u>total derivative</u> (dS/dC) of the health production function with respect to C [called the “dose-response” function]
  - Not the same as the <u>partial derivative</u> ($\partial S/\partial C$) [also called the health production function]

- **<u>Solution:</u>**
- $\Rightarrow$ Derive expression for MWTP that does not require to estimate partial derivative of the health production function

A Practical Expression for MWTP:

$$MWTP = \underbrace{p_W \frac{dS}{sC}}_{\substack{\text{Economic value of} \\ \text{change in sick time} \\ \text{(lost work days + lost leisure)}}} + \underbrace{p_M \frac{\partial M^*}{\partial C}}_{\substack{\text{Change in expenditure on} \\ \text{mitigating activities} \\ \text{(e.g., medications)}}} + \ldots$$

$$- \underbrace{\frac{\partial U}{\partial S} \frac{1}{\lambda} \frac{dS}{dC}}_{\substack{\text{Monetized value of disutility} \\ \text{of illness (or death).} \\ \text{Note that } \frac{\partial U}{\partial S} < 0}}$$

Model: Interpretation

- Three terms, each valued in dollars, all can be measured:
  - Value of lost productive time (e.g., hospital visit expenditures)
  - Value of mitigating investments (e.g., medications)
  - Value of disutility of sickness (e.g., monetized mortality)
- $\Rightarrow$ **This paper can make progress on estimating all 3 terms**
- All adjustment could be in “M”, resulting in dS/dC = 0 (“full adaptation”)
  - Thus dS/dC = 0 by itself does not imply MWTP = 0
  - Need to estimate: dS/dC, ∂M/∂C
- <u>Need data on:</u>
- S (mortality, hospitalizations)
- C (NOx, ozone, PM, etc). <u>Plausibly exogenous variation</u>
- Expenditures on “A” and “M”: <u>that is the hard part</u>

Model: Medications Market Not Perfectly Competitive

- 1. Market power: medication price > marginal cost ≈ 0
  - One interpretation is that markups reflect the fact that pharmaceutical firms must invest socially valuable resources to develop medications to counter air pollution
  - With less air pollution less resources spent on such R&D
  - $\Rightarrow$Dynamically, medication purchases still interpretable as a social cost, not a transfer (Finkelstein 2004)

- 2. Patient's medication payment ≠ market (listed) price
  - Out-of-pocket payment ≈ 10-20% of listed price
  - $\Rightarrow$ Private WTP for medications likely smaller than the medication transacted price
  - $\Rightarrow$ Defensive component of social WTP for clean air is measured by the transacted price of medications taken in response to air pollution

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1. Medication Data

- Thompson Reuters Marketscan <u>2001-2007</u>
  - From employees & dependents at 18 large firms
  - Balanced panel of firms, unbalanced panel of persons
  - Transaction-level data on each medication purchase (>22 million person-seasons, >100 million purchases)

- Confidential, restricted-access, expensive data
  - Key fields: Home county, Prescription date, Cost=actual payment from purchaser (transacted price = total payment from consumer and insurer to the medication provider), National Drug Code

- Not linked to disease classification (ICD)
  - Use published lists to identify respiratory conditions

2. Hospital Visit Data

- Same Marketscan extract as medications
- Follow MarketScan methods to extract emergencies from inpatient & outpatient events
- Emergencies have International Classification of Disease codes
- Measure of hospital visit costs includes all charges from the hospital to the insurer and patient.

3. Mortality Data

- Multiple Cause of Death files:
  - From US death certificates, separate observation per event
  - Key fields: County of residence & occurrence, International classification of disease code, exact date of death, age

- Public files have no geocodes (not even state) starting in 2005, no exact date of death since 1988

- We access confidential versions through Census Research Data Center and an agreement with NCHS
  - Each output undergoes a disclosure process

4. Pollution Emissions Data

- EPA Clean Air Markets Division:
  - Unit-level daily totals of all measured pollutants (NO_x, SO_2, CO_2)
  - 97% of NO_x data from Continuous Emissions Monitoring Systems (CEMS)
  - NOx, SO_2 very accurate. CO_2 from engineering estimates

- Restrict to Acid Rain Units:
  - Includes almost all NBP emissions
  - These units report all year (Jan-Dec)
  - The few NBP-only units only report summer emissions (May-Sept) are not used in this study

5. Ambient Pollution Data

- Extract all pollutants with adequate data (Ozone, CO, NO_2, $PM_{2.5}$, PM_{10}, SO_2)
  - From EPA detailed Air Quality System
  - Hourly or daily readings from population-based monitors

- Selection rule: a monitor must have valid readings for 47 weeks of each year 2001-2007
  - Excludes many ozone monitors which operate only in summer
  - Similar results with other selection rules

- Main ozone standard is 8-hour daily maximum
  - Highest 8-hour rolling average within each day
  - This is what the EPA regulates under CAA

6. Weather Data

- Monitor-level records from National Climate Data Center:
  - Temperature (mean of daily max & min)
  - Precipitation (hundred inches per day)
  - Dew Point Temperature (humidity, measured in degrees)

- Use inverse distance weight to construct county-day measures

- Temperature and dew point temperature: 20 measures each
  - Share of days in each county-season-year which fall in each of 20 quantiles of the overall distribution for temperature or dew point temperature

Data Collection: Records Linked by County-Day

1. Emitted Pollution Data

CEMS Unit-level daily totals (NO_x, SO_2, CO_2)

2. Ambient Pollution Data

Daily monitor readings (Ozone, PM, etc)

Population-based

Used for CAA enforcement

3. Weather Data (NCDC)

Daily monitor readings (Temperature, Rain, Dewpoint)

4. Medication Data

Marketscan (Medstat) 2001-07

From employees/dependents at 18 large firms (>22 Mil. person×season×year records)

Data on each medication purchase, at *transacted* price (>100 Mil. transactions)

National Drug Code (NDC) information. (Data do not identify the specific condition for which a medication was prescribed)

5. Hospital Visit Data

Same Marketscan extract as medications

Follow MarketScan methods to extract emergencies from inpatient & outpatient events

6. Mortality Data

MCOD Files, 1997-2007

All deaths in US, reports age, county and cause, and exact date

Data Summary: Mean Summer Values Across Counties

[Table 1: Averages for 2001-2007]

	Counties With Data (1)	Mean (2)	s.d. (3)
Pollution Emissions (000's of tons/summer)			
NO_x Emissions	2,539	0.52	(1.99)
SO_2 Emissions	2,539	1.50	(6.52)
CO_2 Emissions	2,539	384	(1,299)
Air Quality (Ambient Pollution)			
Ozone 8-Hour Value	168	48.06	(9.28)
Ozone Days ≥65 (ppb)	168	23.60	(22.64)
Weather			
Temperature (ºF)	2,539	70.59	(5.79)
Precipitation (1/100")	2,539	11.46	(5.37)
Dew Point Temp. (ºF)	2,539	57.76	(7.91)
Medication Costs ($ Per Person)			
All	2,435	377.56	(338.66)
Copayment	2,435	79.10	(59.21)
Respiratory or Cardio.	2,435	119.60	(131.25)
Hospitalizations ($ Per Person)			
All	2,435	593.93	(2,501.71)
Respiratory or Cardio.	2,435	117.11	(902.93)
Mortality (Deaths Per 100,000 People)			
All	2,539	402.42	(121.32)
Respiratory or Cardio.	2,539	180.80	(69.93)

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Econometric Approach:

- Unit of observation: county*ozone season*year

- Use DDD model since it closely reflects NBP market design
  - NBP / Non-NBP states, Pre/Post 2003, Summer/Winter:

$$\boxed{\begin{aligned} Y_{cst} = {} & \gamma_1 NBP_c \times SUMMER\ OZ_s \times POST_t + \\ & W_{cst}^{'}\beta + \mu_{ct} + \eta_{st} + \upsilon_{cs} + \varepsilon_{cst} \end{aligned}}$$

  - c – county; s – season (winter/summer); t – year
  - Fixed effects: county-year; season-year; county-season
  - W_{cst} are controls (eg, weather)

Econometric Approach (ctd):

- Grouped data reflecting different numbers of underlying observations:
  - Regression weights proportional to number of underlying observations
  - Weight differs by outcome: (e.g., persons v. pollution readings)

- Inference: allow arbitrary correlation in errors within state*season
  - NBP market only affected pollution in summer (i.e., state*season is level at which treatment varies)
  - Appendix also shows standard errors clustered at county, state, and MSA level

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NBP Impact on Emitted Pollution (Table 2)
[coefficients expressed in 1000 tons]

	(1)	(2)	(3)	(4)	(5)
<u>A. Pollution Emissions</u>					
1. NO_x	-0.36***	-0.37***	-0.36***	-0.33***	-0.42***
	(0.05)	(0.06)	(0.07)	(0.07)	(0.11)
2. SO_2	-0.08**	-0.12*	-0.07	-0.07**	-0.04
	(0.04)	(0.07)	(0.05)	(0.03)	(0.13)
3. CO_2	-3.34	-18.57	-5.00	-12.00*	-74.01
	(4.38)	(16.20)	(6.04)	(6.61)	(52.46)
County-by-Season FE	x	x	x	x	x
Season-by-Year FE	x	x	x	x	x
State-by-Year FE	x	x			
County-by-Year FE			x	x	x
Detailed Weather Controls		x	x	x	x
Data Begins in 2001				x	x
Weighted by Emission/Pollution	x	x	x	x	
Weighted by Population					x

NBP Impact on Ambient Ozone (Table 2)

[Ozone 8-hour value in ppb]

	(1)	(2)	(3)	(4)	(5)
B. Air Quality (Ambient Pollution)					
4. Ozone 8-Hour Value	-2.91***	-3.70***	-2.67***	-3.09***	-3.13***
	(0.77)	(1.23)	(0.73)	(0.53)	(0.51)
5. Ozone Days ≥ 65 ppb	-7.40***	-8.59***	-7.98**	-8.95***	-9.80***
	(2.50)	(2.79)	(3.02)	(2.51)	(2.21)
County-by-Season FE	x	x	x	x	x
Season-by-Year FE	x	x	x	x	x
State-by-Year FE	x	x			
County-by-Year FE			x	x	x
Detailed Weather Controls		x	x	x	x
Data Begins in 2001				x	x
Weighted by Emission/Pollution Monitors	x	x	x	x	
Weighted by Population					x

NBP Impact on Other Ambient Pollutants (Table 2)

	(1)	(2)	(3)	(4)	(5)
<u>B. Air Quality (Ambient Pollution)</u>					
6. CO: Carbon Monoxide (ppm)	-0.05**	-0.01	-0.04	-0.02	-0.01
	(0.02)	(0.03)	(0.03)	(0.02)	(0.02)
7. SO_2: Sulfur Dioxide (ppb)	0.16	0.31	0.13	0.17	0.23
	(0.12)	(0.23)	(0.19)	(0.19)	(0.16)
8. NO_2: Nitrogen Dioxide (ppb)	-1.13***	-0.87	-1.07***	-0.94***	-1.23**
	(0.21)	(0.72)	(0.35)	(0.33)	(0.48)
9. $PM_{2.5}$: Particulates Less than 2.5 μm ($\mu g/m^3$)	---	---	---	-0.31	-0.86***
	---	---	---	(0.30)	(0.26)
10. PM_{10}: Particulates Less than 10 μm ($\mu g/m^3$)	---	---	---	-1.29	-1.07
	---	---	---	(0.96)	(1.09)
County-by-Season FE	x	x	x	x	x
Season-by-Year FE	x	x	x	x	x
State-by-Year FE	x	x			
County-by-Year FE			x	x	x
Detailed Weather Controls		x	x	x	x
Data Begins in 2001				x	x
Weighted by Emission/Pollution Monitors	x	x	x	x	
Weighted by Population					x

Summary: NBP Impact on Emitted & Ambient Pollution

- NBP market decreased NO_x emissions in the average county by 330-420 tons
  - Total reduction ≈ 400,000 - 500,000 tons / year
  - No effect on emitted SO2 and CO2

- NBP market decreased ozone concentrations
  - mean summer ozone by about 3 ppb (or 6-7% of baseline)
  - number of high-ozone days by about 9-10 (40% of baseline)

- Other ambient air pollutants:
  - CO, PM10, SO2: no effect
  - NO2 (part of NOx): 6-7% reduction, but no health effect
  - PM2.5: 6% reduction; significance depends on specification

NBP Impact on Log Medication Costs (Table 3)
[$2015, 2001-2007]

	(1)	(2)	(3)	(4)
A. All Medications				
1. All Medications	-0.008	-0.022	-0.016***	-0.015**
	(0.010)	(0.021)	(0.006)	(0.007)
Sample Size	30,926	30,926	30,926	2,338
County-by-Season FE	x	x	x	x
Season-by-Year FE	x	x	x	x
State-by-Year FE	x	x		
County-by-Year FE			x	x
Detailed Weather Controls		x	x	x
Only Counties With Ozone Monitors				x
Weighted by Population	x	x	x	x

Additional results (appendix)

Log(Copay) = -0.015 (0.006)**
Log(Prescriptions) = -0.016 (0.006)**

NBP Impact on Log Medication Costs (Table 3)

	(1)	(2)	(3)	(4)
<u>B. Specific Types of Medications</u>				
2. Respiratory or Cardiovascular	-0.005	-0.017	-0.020***	-0.006
	(0.013)	(0.025)	(0.007)	(0.009)
3. Non-Respiratory and Non-Cardiovascular	-0.010	-0.025	-0.015**	-0.019**
	(0.010)	(0.021)	(0.006)	(0.008)
Sample Size	30,926	30,926	30,926	2,338
County-by-Season FE	x	x	x	x
Season-by-Year FE	x	x	x	x
State-by-Year FE	x	x		
County-by-Year FE			x	x
Detailed Weather Controls		x	x	x
Only Counties With Ozone Monitors				x
Weighted by Population	x	x	x	x

Additional results (appendix)

Log(Respiratory Short-Acting Meds) = -0.024 (0.018)
Log(Respiratory Long-Term Meds) = -0.021** (0.008)

NBP Impact on Mortality Rate per 100,000 (Table 4)

	(1)	(2)	(3)	(4)	(5)
A: All Deaths					
1. All Deaths	-2.14**	-3.12	-1.67**	-5.23***	-2.78*
	(0.94)	(3.31)	(0.78)	(1.56)	(1.48)
C. All Causes of Death, by Age Group					
5. Age 0 (Infants)	-2.26	-8.87	-3.50	6.68	-10.71
	(3.90)	(7.38)	(6.14)	(10.37)	(9.50)
6. Ages 1-64	-0.09	-1.72	-0.26	-0.35	-0.80
	(0.32)	(1.06)	(0.46)	(1.20)	(0.85)
7. Ages 65-74	-1.83	-16.39	-2.17	-9.36	-0.99
	(4.96)	(12.00)	(6.01)	(10.11)	(6.03)
8. Ages 75+	-39.25***	-41.64*	-21.13**	-92.23***	-29.23
	(8.39)	(21.02)	(10.46)	(17.70)	(18.74)
Estimated Change in 2005 Deaths	-3,401	-3,609	-1,831	-7,993	-2,533
Sample Size	55,858	55,858	55,858	3,124	35,546
County-by-Season FE	x	x	x	x	x
Season-by-Year FE	x	x	x	x	x
State-by-Year FE	x	x			
County-by-Year FE			x	x	x
Detailed Weather Controls		x	x	x	x
Counties With Ozone Monitors				x	
Data Begins in 2001					x

NBP Impact on Mortality Rate per 100,000 (Table 4)

	(1)	(2)	(3)	(4)	(5)
A: All Deaths					
1. All Deaths	-2.14**	-3.12	-1.67**	-5.23***	-2.78*
	(0.94)	(3.31)	(0.78)	(1.56)	(1.48)
B: Specific Causes of Death					
2. Respiratory or Cardiovascular	-0.75	-1.67	-0.57	-2.29**	-1.16
	(0.49)	(1.64)	(0.66)	(0.92)	(1.05)
3. Non-Respiratory and Non-Cardio.	-1.40**	-1.45	-1.10**	-2.94***	-1.62*
	(0.57)	(1.83)	(0.48)	(0.90)	(0.84)
4. External	0.57**	-0.02	0.32	0.28	0.37
	(0.23)	(0.50)	(0.33)	(0.60)	(0.44)
County-by-Season FE	x	x	x	x	x
Season-by-Year FE	x	x	x	x	x
State-by-Year FE	x	x			
County-by-Year FE			x	x	x
Detailed Weather Controls		x	x	x	x
Counties With Ozone Monitors				x	
Data Begins in 2001					x

Near Term Mortality Displacement

- Displacement: NBP market prevented deaths which would have occurred during the summer months (May-Sept) and move them to the non-ozone season (Oct-Dec)
  - People who die from air pollution may have pre-existing medical conditions which decrease their life expectancies
- We explored the empirical relevance of this short-term ‘seasonal’ displacement using a “annual” DD model:
  - Similar point estimates as in the DDD model, but with less precision
- $\Rightarrow$ This research design lacks power to measure the effect of air pollution on life expectancy beyond a 5-month period
  - *Note: prior literature looks at displacement effects over windows of a few days to a few weeks*

Instrumental Variables Estimates

- $\Rightarrow$ Use Summer*Post*NBP as IV for NOx emissions
  - Identify causal effect of NOx emissions on health and defensive investments thorough quasi-experimental variation in NOx generated by NBP
- $\Rightarrow$ Use Summer*Post*NBP as IV for Ozone concentration
  - Table 2: Change in NOx emissions primary channel for documented change in Ozone concentrations
  - But change in NOx emission can also change PM2.5 concentrations. Interpretation of Ozone IV estimates not as clear cut
- Sample: 2001-2007
- Report estimates of NOx effect for all study counties (~2500) and for ozone-monitored counties (168)

IV Estimates of Effect of NOx Emissions and Ozone Concentrations (Table 5)

[coefficients in (1), (2a), (2b) multiplied by 1000]

	Log Medication Costs			All-Cause Mortality		
	All Counties	Counties with NO_x Emissions	Ozone Monitored Counties	All Counties	Counties with NO_x Emissions	Ozone Monitored Counties
	(1)	(2a)	(2b)	(3)	(4a)	(4b)
<u>B: 2SLS</u>						
NOx Emissions	22.37	11.93**	---	5.74	5.98*	---
	(13.83)	(5.74)	---	(3.83)	(3.10)	---
Δ 10% effect	*0.14%*	*0.07%*		*0.07%*	*0.07%*	
8-Hour Ozone	---	---	5.73**	---	---	2.45*
	---	---	(2.24)	---	---	(1.24)
Δ 10% effect			*2.8%*			*3.0%*
Days ≥65 ppb	---	---	1.55**	---	---	0.79*
	---	---	(0.65)	---	---	(0.45)
Δ 10% effect			*0.37%*			*0.46%*

Outline of Talk

- 1. Background on ozone and its effects on health
- 2. Details on NO_x Budget Trading Program
- 3. Theoretical framework
- 4. Data
- 5. Econometric approach
- 6. Results
- 7. Interpretation and conclusions

Aggregate Abatement Costs and Health Benefits of NBP
[Table 6, $2015]

	Medications ($ Million)	Mortality:		Total ($ Million)
		Number of Deaths	Monetized Value ($ Million)	
	(1)	(2)	(3)	(4)
A. An Upper Bound Estimate of NBP's Social Costs				
Upper Bound Per Year				$1,076
Upper Bound, 2003-2007 Total				$4,843
B. Estimates of the NBP's Benefits				
Total Per Year	$820	2,613	$1,487	$2,307
Total 2003-2007	$3,690	11,758	$6,690	$10,380
C. The Annual Social Benefits of NO_x Reductions (Million Tons)				
All Counties	$1,146	7,792	4,433	$5,579
Counties with Ozone Monitors	$7,309	31,180	$17,739	$25,048
D. The Social Benefits of Ozone Reductions in the Eastern US (ppb)				
1 ppb Ozone Decrease	$294	3,326	$1,892	$2,186
1 Less Day With Ozone > 65 ppb	$79	1,072	$610	$690

Note: We use an age-adjusted VSL to monetize the reduction in mortality (VSL of age 75+ is about $300,000). Based on Ashenfelter & Greenstone's (2004) VSL ($2.27 Mil. ($2015)). Larger estimates when using EPA's VSL of ($8.7 Mil. ($2015))

Note: if counting only the copay component of medication costs, the annual NBP benefit is $1,659 Mil.

Conclusion:

- First study to provide a complete assessment, derived from real-world data, of the direct health benefits and avoided defensive expenditures associated with a market-based environmental regulation, the NO_x Budget Trading Program

- NBP market can also be used to generate important and new IV estimates of the effect of NOx emissions on health and defensive outcomes
  - Causal links in urban areas (ozone monitored & NOx emitting counties)
  - We argue that these effects are to a first order driven by causal ozone channel
  - But care is needed in making this interpretation

Conclusion:

- Monetized value of studied health benefits twice as large NBP abatement costs
  - Reduction in medication expenditures <u>alone</u> corresponds to \$800 million per year while the upper bound estimate of abatement costs (\$1100 million per year)
  - But defensive behavior still incomplete: $\approx$ 65% of benefits from mortality reduction

- One limitation of this study is that it overlooks non-health effects which may have their own compensatory responses
  - Possible impacts on agricultural yields
  - Possible impacts on worker productivity