Cap-and-Trade in Practice:

An Analysis of North Carolina's Clean Smokestacks Act

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Cap-and-Trade vs. Command-and-Control

- **Problem**: Negative externality from pollution harms society
- **Policy Solutions**: Command-and-control, Emissions Tax, & Cap-and-Trade

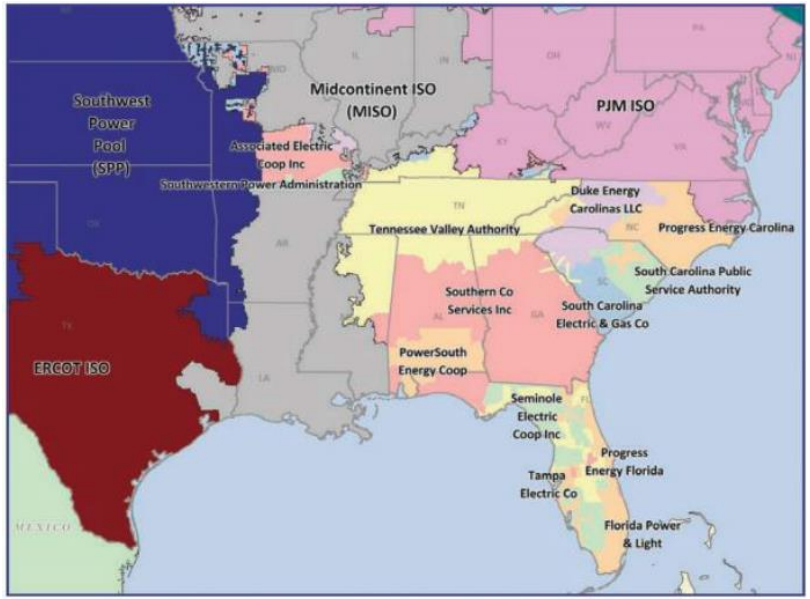
- **Existing Cap-and-Trade Programs:**
  - Acid Rain (SO_2) Program, Carlson et al (2000); RECLAIM, Fowlie et al (2012); EU-ETS, Bushnell et al (2013); RGGI, Murray and Maniloff (2015)
  - North Carolina Clean Smokestacks Act (CSA)

- **Research Questions**:
  - How effective is the CSA in reducing emissions of SO_2 and NO_x at targeted plants?
  - How prevalent is leakage when CSA plants are allowed to shift production to unregulated plants?
  - How does the geographic distribution of emissions and subsequent damages change after the CSA?

Clean Smokestacks Act (CSA)

- NC passed in 2002, reporting starts in 2003, first cap 2007
- Targets SO_2 and NO_x emissions
- Affects only coal-plants with >25 MW nameplate capacity
  - Utility level caps (Duke Power and Progress Energy)
- Cap-and-trade with limited trading:
  - Emissions can be “traded” across plants within the same utility but not between utilities
- Minimum compliance cost requirement and rates frozen
- Compliance cost recovery mechanism (amortized tax credit)
- Existing analyses:
  - Hoppock et al (2012), Andrews (2013)

Market Structure

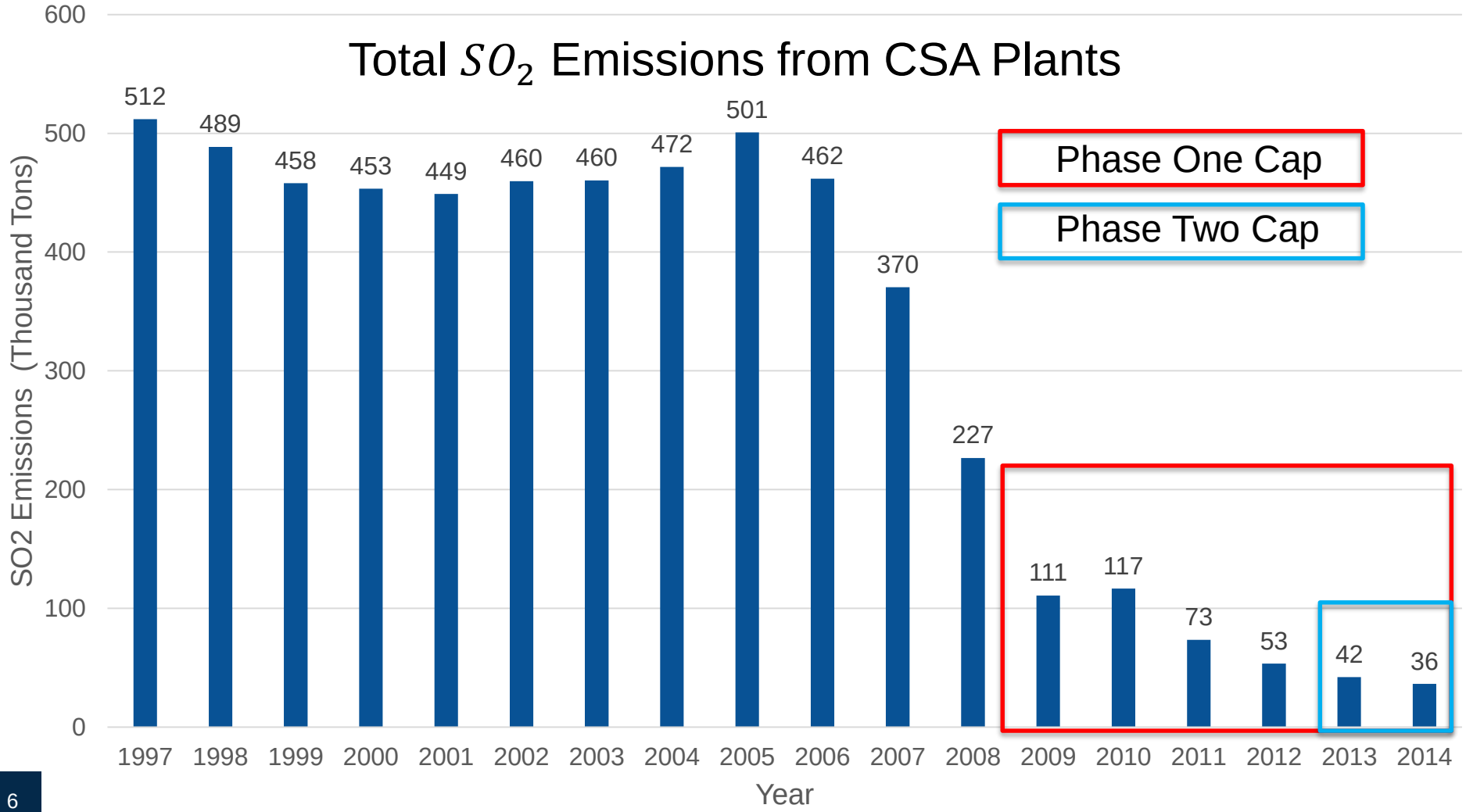


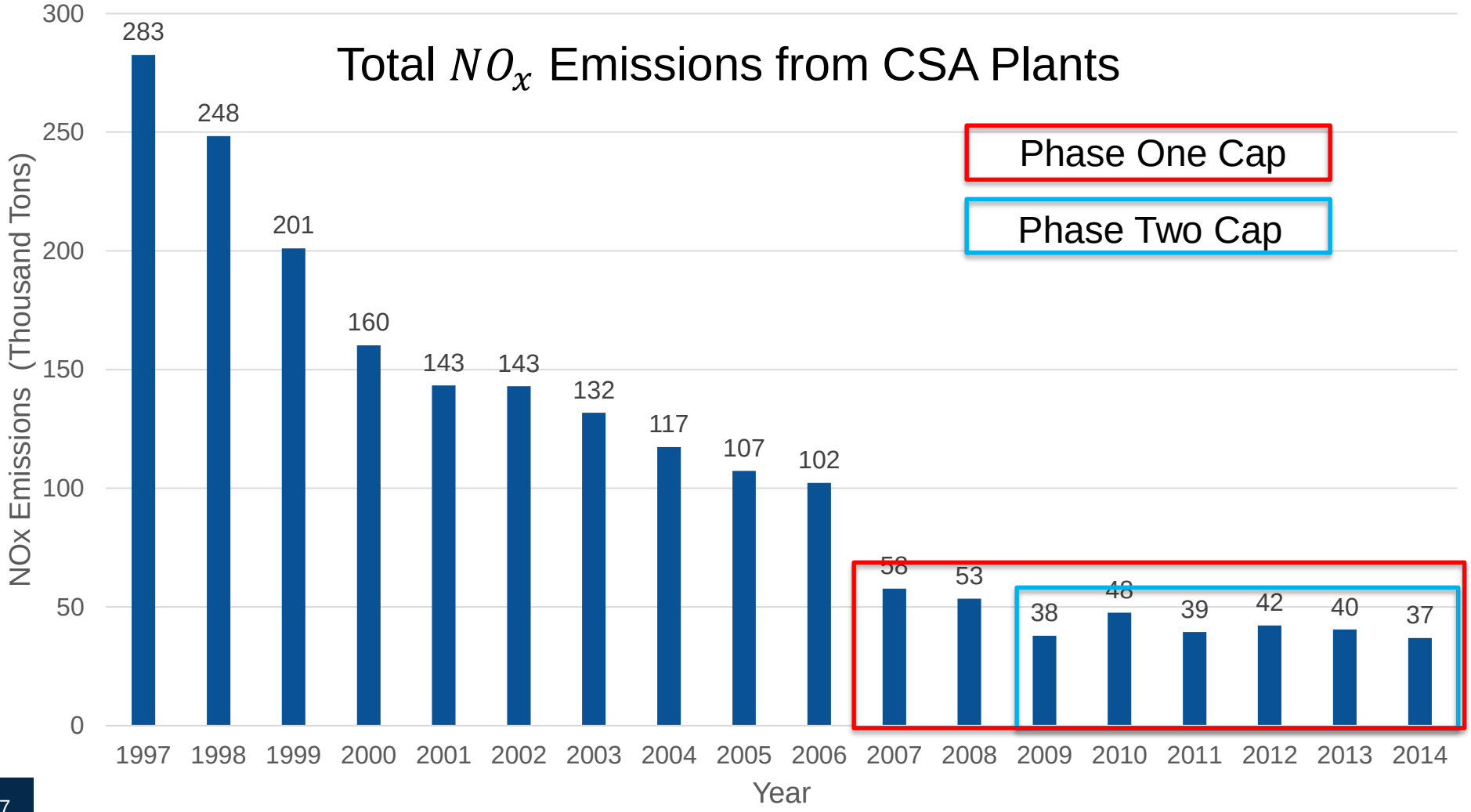
- Regulated rates:
  - Dependent on costs
    - (e.g. capital investments)
  - Rates expected to fall pre-CSA
- Interconnected grid:
  - Trade of electricity can occur throughout region
- Ease of trade:
  - South Carolina
  - Tennessee (TVA)
  - Virginia (PJM)

Data: U.S. Continuous Emissions Monitoring System (CEMS)

- Unit of observation:
  - Hourly-unit level
  - Aggregated to annual-plant level
- Observation window:
  - 1997-2014
- Pollutants:
  - SO_2
  - NO_x
  - CO_2

- Emissions and Generation Resource Integrated Database (eGRID)
  - Plant Characteristics:
    - Fuel type
    - Nameplate Capacity
    - Number of Generators
    - Number of Boilers
    - Operator information
    - Regulatory region


Total SO_2 Emissions from CSA Plants
SO2 Emissions (Thousand Tons)
600
500
400
300
200
100
0
512
489
458
453
449
460
460
472
501
462
370
227
111
117
73
53
42
36
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Year
Phase One Cap
Phase Two Cap


Total NO_x Emissions from CSA Plants
Phase One Cap
Phase Two Cap
NOx Emissions (Thousand Tons)
300
250
200
150
100
50
0
283
248
201
160
143
143
132
117
107
102
58
53
38
48
39
42
40
37
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Year

Empirical Strategies

- **Effectiveness**
  - **Difference-in-Differences (DiD)**
    - Control Group: All coal plants in U.S. that are not in bordering states, RECLAIM, or RGGI
  - **Synthetic Control Method (SCM)**
    - Number of boilers, name plate capacity, and number of generators
- **Leakage**:
  - DiD with SC, TN, and VA as separate treatment groups.
- **Damage Estimates:**
  - Plant-specific effects estimated using SCM
  - Use MD estimates from Muller and Mendelsohn (2009)

Effectiveness (DiD): SO_2 and NO_x Emissions

	SO_2	$ln(SO_2)$		NO_x	$ln(NO_x)$	
Level	-4.353	-1.318***	-73.23%	1.487	-0.627***	-46.58%
	(3.527)	(0.117)	-	(1.623)	(0.0701)	-
Rate	-0.288***	-1.119***	-67.34%	-0.0738***	-0.470***	-37.50%
	(0.0501)	(0.0737)	-	(0.0219)	(0.0595)	-

Note: State-clustered standard errors in parentheses.
*** p<1%, ** p<5%, and * p<10%.
Control group excludes neighboring states, RECLAIM, and RGGI states.

Effectiveness: Difference-in-Differences

- **Advantages:**
  - Simple to estimate
  - Linear regressions are familiar to policy/decision makers
- **Disadvantages:**
  - Sensitive to control group selection
    - Hunt for the ideal control group
  - Standard DiD does not control for time-varying unobservable characteristics
    - Potential source of bias

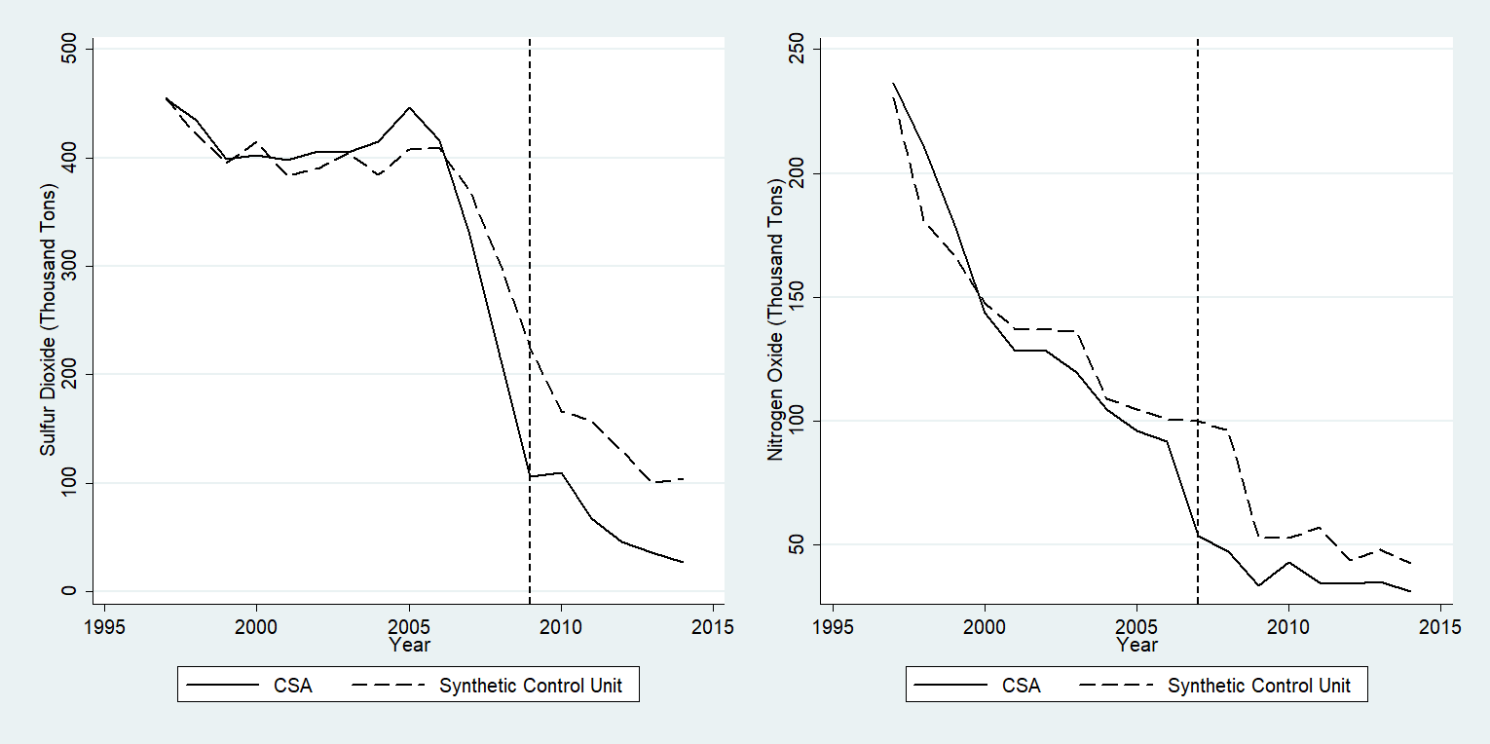
Effectiveness: Synthetic Control Method

- Similar to difference-in-differences
  - Still exploiting the difference between pre/post and treated/untreated
- Estimating a counterfactual *(Synthetic Control Unit)*:
  - All untreated plants are now included in the control group and given a weight
  - Weight matrix is defined such that the pre-treatment control group closely matches the pre-treatment treated group (CSA plants)
  - Weight matrix then used to predict outcome of interest in post-treatment period for the treatment group

Effectiveness: Synthetic Control Method

- **Advantages:**
  - Easy to interpret
  - Addresses two concerns with DID
    - Control group selection (takes a data driven approach)
    - Control for time-varying unobservable characteristics
- **Disadvantages:**
  - Traditional large scale asymptotic inference does not apply
    - Placebo/Permutation tests
  - Requires a lengthy, pre-treatment period for sufficient weighting/matching
  - Computationally more demanding than DID

Effectiveness (SCM): SO_2 & NO_x Emissions



Leakage: Difference-in-Differences

- **Potential Leakage/Spillover Groups:**
  - South Carolina ($\boldsymbol{\beta_4}$)
  - Virginia ($\boldsymbol{\beta_5}$)
  - Tennessee ($\boldsymbol{\beta_6}$)

- **Baseline Leakage DiD:**

$$y_{it} = \beta_0 + \beta_1 CSA_i + \beta_2 Post_t + \beta_3 CSA_i * Post_t +$$
$$\boldsymbol{\beta_4}\, SC_i * Post_t + \boldsymbol{\beta_5}\, VA * Post_t + \boldsymbol{\beta_6}\, TN * Post_t + \varepsilon_{it}$$

Leakage (DID): SO_2 and NO_x Emissions

		SC Level	SC Log	VA Level	VA Log	TN Level	TN Log
SO_2	CSA Effect	2.076	-0.0256	1.768	-0.0645	-71.99***	-0.518***
		(1.983)	(0.103)	(1.855)	(0.101)	(2.069)	(0.107)
NO_x	CSA Effect	1.372*	0.00241	0.871	0.0826*	-34.04***	-0.476***
		(0.741)	(0.0448)	(0.666)	(0.0438)	(0.786)	(0.0458)

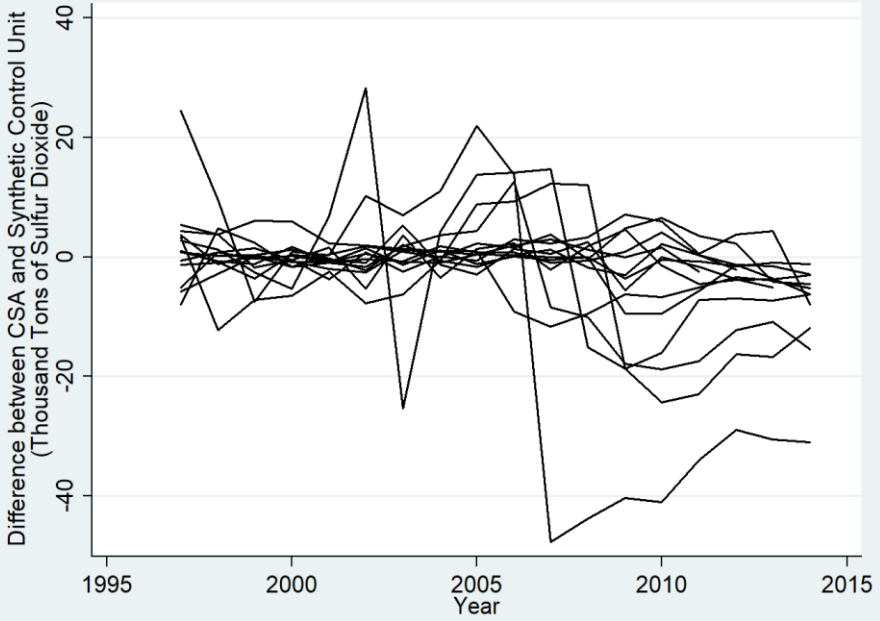
Note: State-clustered standard errors in parentheses. *** p<1%, ** p<5%, and * p<10%.

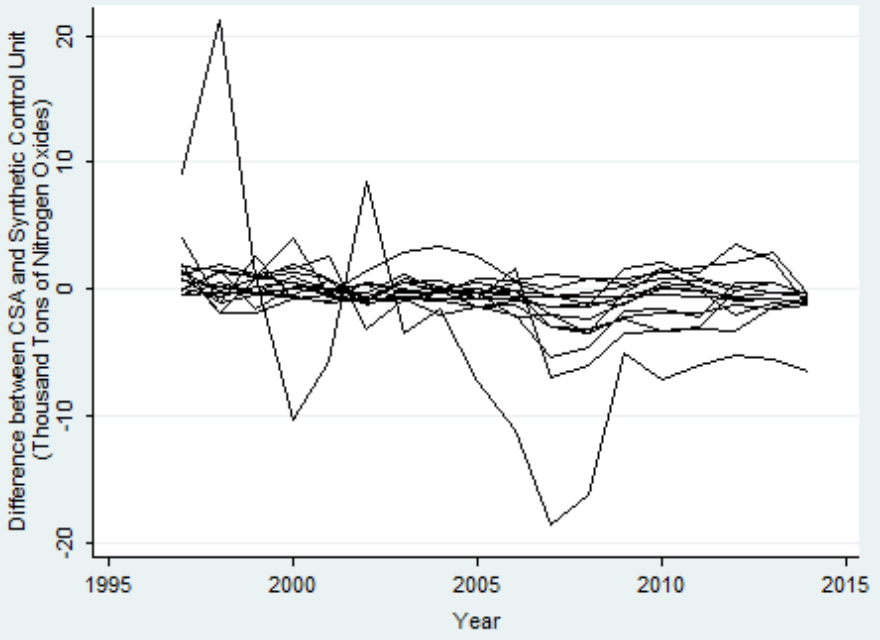
Damages: Synthetic Control Method

- **Plant-Specific Treatment Effects:**
  - *Step 1*: Define each CSA-plant as a separate treatment group
  - *Step 2*: Apply Synthetic Control Method
  - *Step 3*: Iterate over each plant for each outcome variable (i.e. pollutants)
  - *Step 4*: Calculate plant-specific effect (difference between plant and SCU)

- **Estimating Damages:**
  - Apply MD estimates from Muller and Mendelsohn (2009)
    - County-level MD estimates by effective stack height
  - Aggregate across all CSA-plants from 2005 to 2014

Damages (SCM): Plant-Specific Effects





Estimated Benefits (Avoided Damages)

	Gross Benefits (2014$)
SO_2	$ 1.84 Billion
NO_x	$ 0.04 Billion
Total	**$ 1.88 Billion**

Note: *Benefits* are estimates of avoided damages due to reductions in emissions.

Sensitivity Analysis (SCM): Placebo Tests

- Define each control unit as the treatment group
- Apply SCM
- Iterate over each potential control unit
- Collect all SCM estimates for the control units into a single distribution
  - Partially represents the distribution of potential counterfactuals
- Significant effect of policy ⇒ Actual treatment group should be an outlier in the distribution of placebos

Sensitivity Analysis (SCM): Placebo Estimates

Conclusions

- ***How effective is the CSA in reducing emissions of SO_2 and NO_x?***
  - ~ 100,000 ton annual reduction in SO_2 emissions
  - ~ 50,000 ton annual reduction in NO_x emissions
  - Both DiD and SCM estimated effects are smaller than previous studies
- ***Were the emissions reductions offset by leakage?***
  - Little to no evidence of leakage (SC and VA)
    - Policy incentive to comply vs. leak
  - Strong evidence of positive spillovers (TN reduced emissions)
    - Due to lawsuit and subsequent settlement
- ***How do damages change after the CSA?***
  - $1.88 billion in avoided damages (gross benefits)

Conclusions

- An imperfect C&T policy can still be an effective C&T policy
- Expectations about regulated rates have an impact on firm decision making
- Aspects of the CSA that can be useful in crafting future C&T policies:
  - Policy aspects factored into firm decision-making:
    - Minimum compliance cost requirements
    - Mechanism for compliance cost recovery
    - Regulated-rates
  - Simplifying the emissions market by placing cap at utility level
    - Alleviates the need for a formal permit market

How can SCM be applied to other problems?

- Requires:
  - Treatment and Control units
  - Multiple pre-treatment periods of observation
  - Characteristics common to both treatment and control units
  - Distinct policy change (treatment)

- Ideal for:
  - Small or aggregate treatment groups
  - Municipal/County/State/Country/Regional level policies
  - Long pre-treatment period of observation

Thank you!

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