Overlapping Environmental Policies and the Impact on Pollution

Kevin Novan

Contributed presentation at the 60th AARES Annual Conference,
Canberra, ACT, 2-5 February 2016

Overlapping Environmental Policies and the Impact on Pollution

Kevin Novan

UC Davis, Agricultural and Resource Economics

Overlapping Policies

Electricity generators emit many pollutants (CO_2, NO_X, etc.)

- Prices have been established for a subset of pollutants
- Almost exclusively using cap-&-trade programs (not pollution taxes)

Overlapping Policies

Electricity generators emit many pollutants (CO_2, NO_X, etc.)

- Prices have been established for a subset of pollutants
- Almost exclusively using cap-&-trade programs (not pollution taxes)

Emission caps are being combined with additional policies:

- e.g., Subsidies for renewable electricity or energy efficiency

Overlapping Policies

Electricity generators emit many pollutants (CO_2, NO_X, etc.)

- Prices have been established for a subset of pollutants
- Almost exclusively using cap-&-trade programs (not pollution taxes)

Emission caps are being combined with additional policies:

- e.g., Subsidies for renewable electricity or energy efficiency

Combined with a binding cap, increasing renewable output...

- Will not affect emissions of capped pollutant
- What happens to the unregulated pollutants?

Overview of Paper

Introduce a simple model of an electricity market:

- Two pollutants: one regulated, one unregulated

- Increasing renewable output can <u>increase</u> pollution

Overview of Paper

Introduce a simple model of an electricity market:

- Two pollutants: one regulated, one unregulated
- ▶ Increasing renewable output can <u>increase</u> pollution

Application to U.S. EPA's NO_X cap-and-trade program:

- How would renewable expansions affect CO_2 and SO_2?
- ▶ SO_2 emissions will <u>increase</u>
- ▶ CO_2 falls – but by <u>much less</u> than previously thought

Single-Period Model

Two Forms of Conventional Generation: X_1 (coal) and X_2 (gas)

$c_i(X_i) =$ convex private costs

$(\mu_1, \mu_2) =$ emission rates of regulated pollutant (*i.e.* NO_X)

$(\rho_1, \rho_2) =$ emission rates of unregulated pollutant (*i.e.* CO_2)

Single-Period Model

Two Forms of Conventional Generation: X_1 (coal) and X_2 (gas)

$c_i(X_i) =$ convex private costs

$(\mu_1, \mu_2) =$ emission rates of regulated pollutant (*i.e.* NO_X)

$(\rho_1, \rho_2) =$ emission rates of unregulated pollutant (*i.e.* CO_2)

Demand and Renewables:

$D =$ demand (perfectly inelastic w.r.t. wholesale price)

$r =$ renewable generation

Single-Period Model

Two Forms of Conventional Generation: X_1 (coal) and X_2 (gas)

$c_i(X_i) =$ convex private costs

$(\mu_1, \mu_2) =$ emission rates of <u>regulated</u> pollutant (*i.e.* NO_X)

$(\rho_1, \rho_2) =$ emission rates of <u>unregulated</u> pollutant (*i.e.* CO_2)

Demand and Renewables:

$D =$ demand (perfectly inelastic w.r.t. wholesale price)

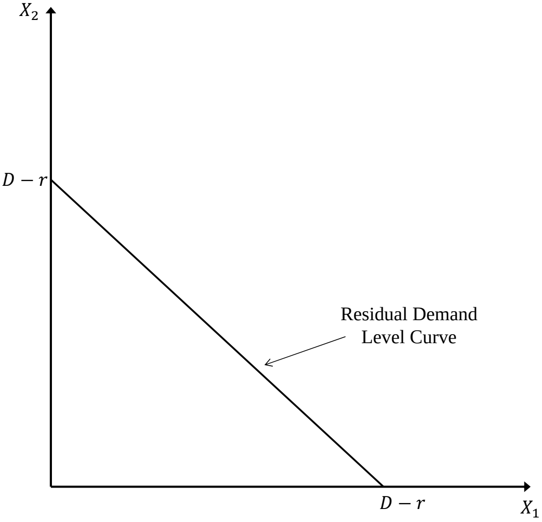
$r =$ renewable generation

Market Clearing Conditions:

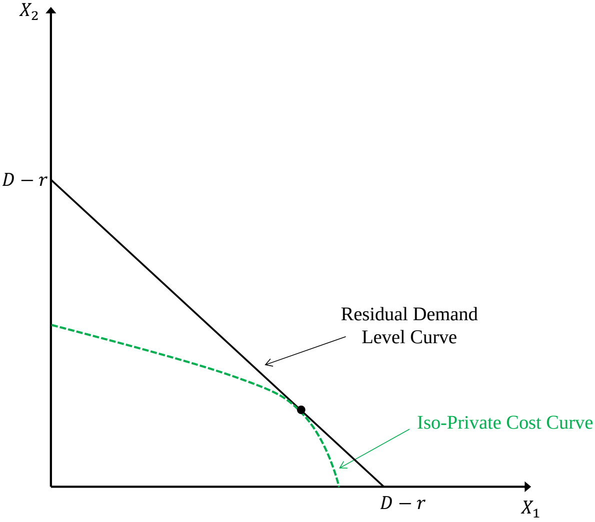
(1) $D - r = X_1 + X_2$

(2) $\mu_1 \cdot X_1 + \mu_2 \cdot X_2 = \bar{\mu}$ *($\bar{\mu}$ is binding pollution cap)*

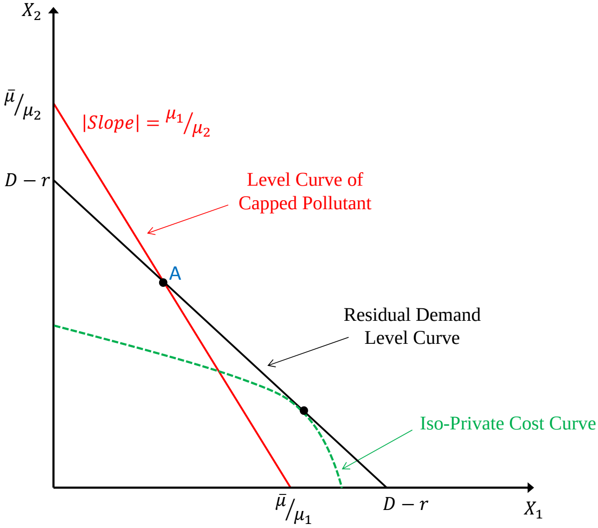
Binding Emission Cap



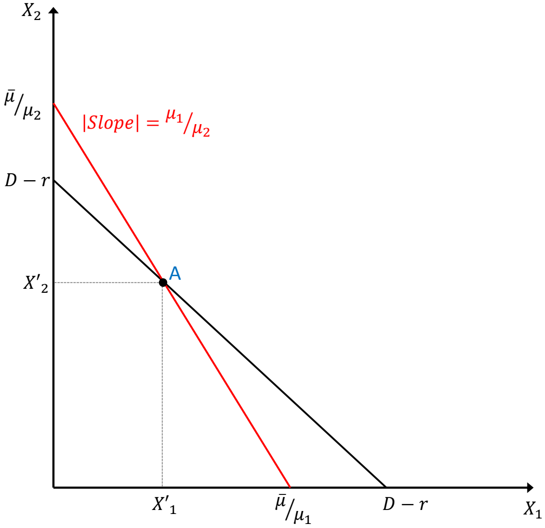
Binding Emission Cap



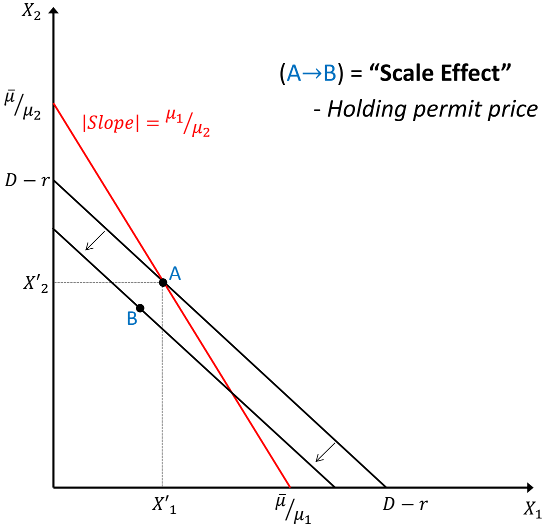
Binding Emission Cap



Binding Emission Cap



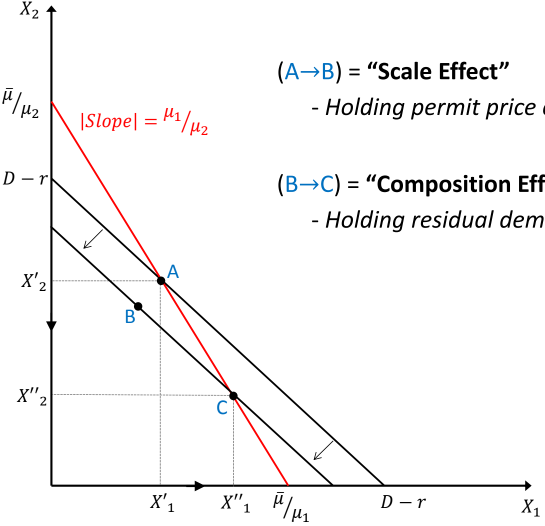
Increase in r or Decrease in D



(A→B) = **"Scale Effect"**

- *Holding permit price constant*

Increase in r or Decrease in D



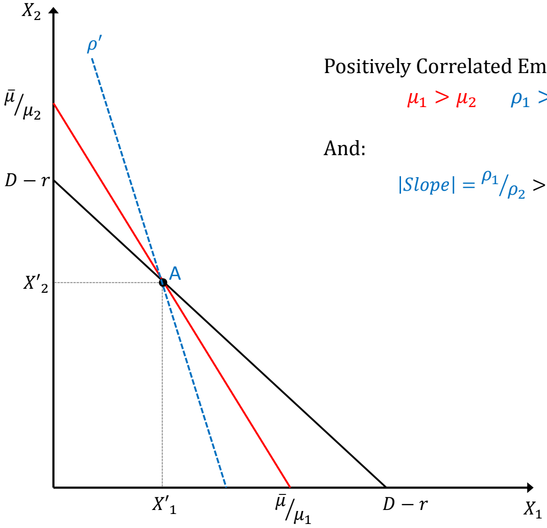
(A→B) = **"Scale Effect"**

- *Holding permit price constant*

(B→C) = **"Composition Effect"**

- *Holding residual demand constant*

Unregulated Pollution Increases



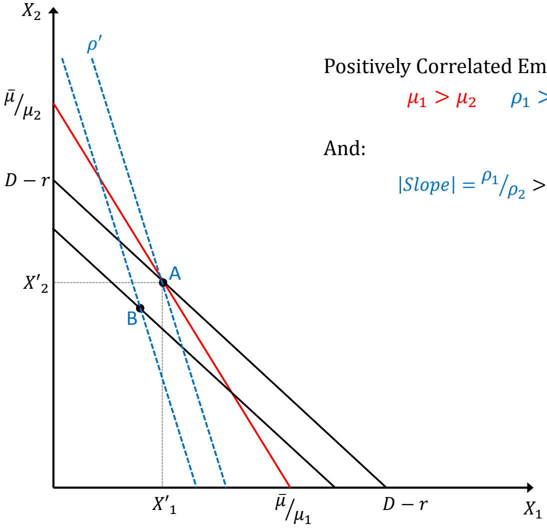
Positively Correlated Emission Rates:

$\mu_1 > \mu_2 \qquad \rho_1 > \rho_2$

And:

$|Slope| = {}^{\rho_1}/_{\rho_2} > {}^{\mu_1}/_{\mu_2}$

Unregulated Pollution Increases



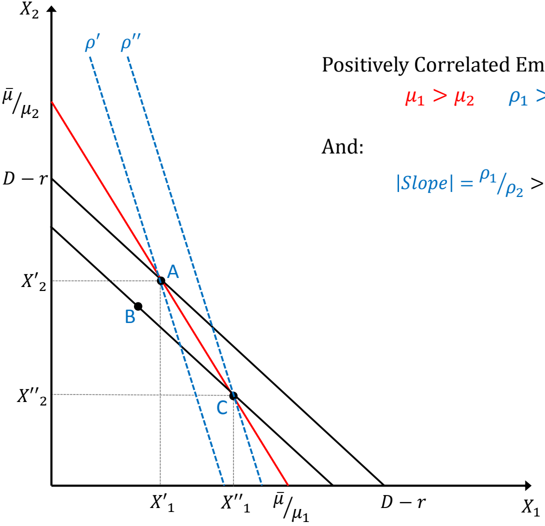
Positively Correlated Emission Rates:

$\mu_1 > \mu_2 \qquad \rho_1 > \rho_2$

And:

$|Slope| = \rho_1/\rho_2 > \mu_1/\mu_2$

Unregulated Pollution Increases



Positively Correlated Emission Rates:

$\mu_1 > \mu_2$ $\rho_1 > \rho_2$

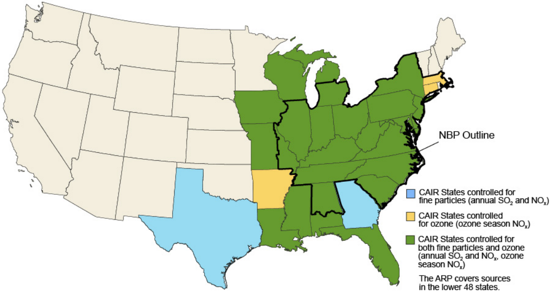
And:

$|Slope| = \rho_1/\rho_2 > \mu_1/\mu_2$

EPA Clean Air Interstate Rule (CAIR)

Thought experiment: Assuming annual NO_X cap is binding...

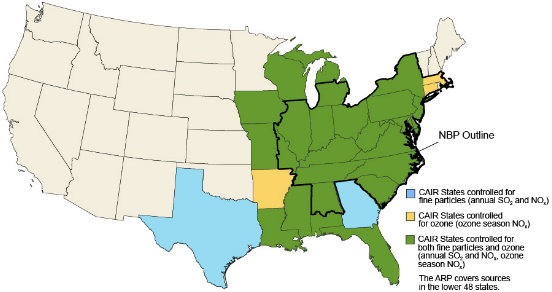
- Add 1,000 MW of solar capacity
- How do annual CO_2 and SO_2 emissions change?



EPA Clean Air Interstate Rule (CAIR)

Thought experiment: Assuming annual NO_X cap is binding...

- Add 1,000 MW of solar capacity
- How do annual CO_2 and SO_2 emissions change?



NO_X price will fall until net $\Delta NO_X = 0$

- Total fossil generation falls, but ratio of coal to gas increases
- In the end, CO_2 falls (slightly) and SO_2 increases

Conclusions

With overlapping cap on a subset of pollutants:

- External benefit of renewables/conservation is small
- Subsidies are a very poor substitute for missing prices

Conclusions

With overlapping cap on a subset of pollutants:

- External benefit of renewables/conservation is small
- Subsidies are a very poor substitute for missing prices

With overlapping tax on a subset of pollutants:

- "Composition Effect" doesn't occur
- Subsidies serve as imperfect substitute for missing prices

Conclusions

With overlapping cap on a subset of pollutants:

- External benefit of renewables/conservation is small
- Subsidies are a very poor substitute for missing prices

With overlapping tax on a subset of pollutants:

- "Composition Effect" doesn't occur
- Subsidies serve as imperfect substitute for missing prices

Policy recommendations:

(1) Just price pollution already!

(2) If we can't – then combine subsidies with taxes (not caps)

(3) If we can't use taxes:

- Set tight price collars / Update caps / Expand 'set-aside' programs

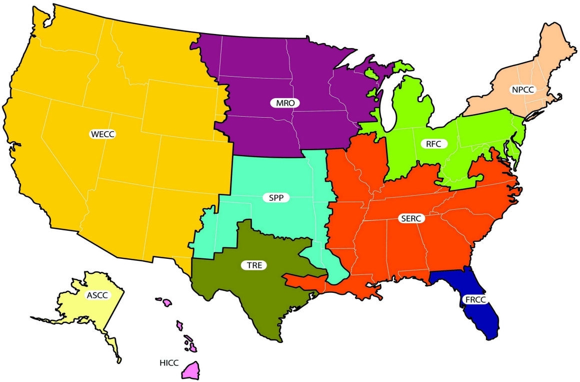
Thank You

Comments/Questions: knovan@ucdavis.edu

EPA's Continuous Emissions Monitoring System (2009-2012)

$$G_t = \text{Hourly fossil generation}$$

$$E_t = \text{Hourly } NO_X\text{, } CO_2\text{, and } SO_2$$



Data

Return

EPA's Continuous Emissions Monitoring System (2009-2012)

$$G_t = \text{Hourly fossil generation}$$

$$E_t = \text{Hourly } NO_X\text{, } CO_2\text{, and } SO_2$$

Emission Rates by Technology

	Combined Cycle	Coal	Other
N	535	1,911	1,029
Median CO_2 Rate (*tons/MWh*)	0.44	1.06	0.71
Median SO_2 Rate (*lbs/MWh*)	0.01	6.79	0.01
Median NO_X Rate (*lbs/MWh*)	0.12	2.85	0.95

 Return

EPA's Continuous Emissions Monitoring System (2009-2012)

$G_t =$ Hourly fossil generation

$E_t =$ Hourly NO_X, CO_2, and SO_2

Emission Rates by Technology

	Combined Cycle	Coal	Other
N	535	1,911	1,029
Median CO_2 Rate (*tons/MWh*)	0.44	1.06	0.71
Median SO_2 Rate (*lbs/MWh*)	0.01	6.79	0.01
Median NO_X Rate (*lbs/MWh*)	0.12	2.85	0.95

To simulate hourly output from 1,000 MW of solar:

- Observe hourly solar capacity factors in Texas
- Capacity factor$_t$ = (Generation$_t$)/(Installed Capacity)

$$r_t = (1{,}000 \text{ MW}) \cdot (\text{Capacity Factor}_t)$$

(1) **Estimate Scale Effect**

◂ Model

- Predict which fossil generators on the margin each hour
- Estimate how much CO_2, SO_2, and NO_X would be reduced by solar

▶ A MWh of solar reduces: 0.7 tons CO_2, 2.4 lbs SO_2, 1.3 lbs NO_X

Overview of Empirical Application

Return

(1) **Estimate Scale Effect**

Model

- Predict which fossil generators on the margin each hour
- Estimate how much CO_2, SO_2, and NO_X would be reduced by solar

▶ A MWh of solar reduces: 0.7 tons CO_2, 2.4 lbs SO_2, 1.3 lbs NO_X

(2) **Estimate Composition Effect**

Strategy

- NO_X price will fall until net $\Delta NO_X = 0$
- Estimate how NO_X permit price decline impacts CO_2 and SO_2

Overview of Empirical Application

Return

(1) **Estimate Scale Effect**

Model

- Predict which fossil generators on the margin each hour
- Estimate how much CO_2, SO_2, and NO_X would be reduced by solar

▶ A MWh of solar reduces: 0.7 tons CO_2, 2.4 lbs SO_2, 1.3 lbs NO_X

(2) **Estimate Composition Effect**

Strategy

- NO_X price will fall until net $\Delta NO_X = 0$
- Estimate how NO_X permit price decline impacts CO_2 and SO_2

▶ Find evidence that NO_X permit decrease will increase CO_2 and SO_2

  - Total fossil generation falls, but ratio of coal to gas increases
  - CO_2 falls by 0.4 tons/MWh, SO_2 increases by 4.8 lbs/MWh

Predicting the "Scale Effect" (for 2009)

Return

$$E_t = f_m(G_t) + \delta_{m,y} + \varepsilon_t$$

$E_t =$ Aggregate hourly NERC NO_X, CO_2, or SO_2

$G_t =$ Aggregate hourly NERC fossil fuel generation (MWh)

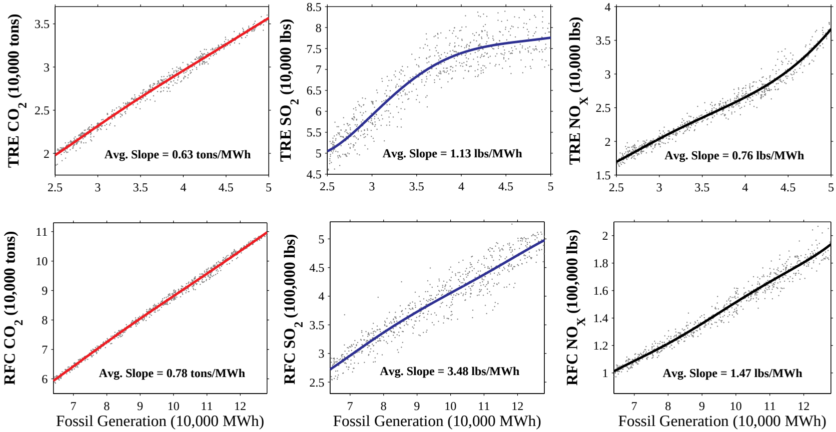
Predicting the "Scale Effect" (for 2009)

◂ Return

$$E_t = f_m(G_t) + \delta_{m,y} + \varepsilon_t$$

$E_t =$ Aggregate hourly NERC NO_X, CO_2, or SO_2

$G_t =$ Aggregate hourly NERC fossil fuel generation (MWh)



Predicting the "Scale Effect" (for 2009)

Return

$$E_t = f_m(G_t) + \delta_{m,y} + \varepsilon_t$$

E_t = Aggregate hourly NERC NO_X, CO_2, or SO_2

G_t = Aggregate hourly NERC fossil fuel generation (MWh)

Scale effect of adding renewable capacity:

$$\Delta(\text{Annual Emissions}) = \sum_{2009} \left[\hat{f}(G_t - r_t) - \hat{f}(G_t) \right]$$

Predicting the "Scale Effect" (for 2009)

Return

$$E_t = f_m(G_t) + \delta_{m,y} + \varepsilon_t$$

$E_t =$ Aggregate hourly NERC NO_X, CO_2, or SO_2

$G_t =$ Aggregate hourly NERC fossil fuel generation (MWh)

Scale effect of adding renewable capacity:

$$\Delta(\text{Annual Emissions}) = \sum_{2009} \left[\hat{f}(G_t - r_t) - \hat{f}(G_t) \right]$$

- Hourly fossil generation falls from (G_t) to $(G_t - r_t)$
- Hourly emissions fall from $f(G_t)$ to $f(G_t - r_t)$

Predicting the "Scale Effect" (for 2009)

Return

$$E_t = f_m(G_t) + \delta_{m,y} + \varepsilon_t$$

$E_t =$ Aggregate hourly NERC NO_X, CO_2, or SO_2

$G_t =$ Aggregate hourly NERC fossil fuel generation (MWh)

Scale effect of adding renewable capacity:

$$\Delta(\text{Annual Emissions}) = \sum_{2009} \left[\hat{f}(G_t - r_t) - \hat{f}(G_t)\right]$$

Key assumption: $f(\cdot)$ does not change as r increases

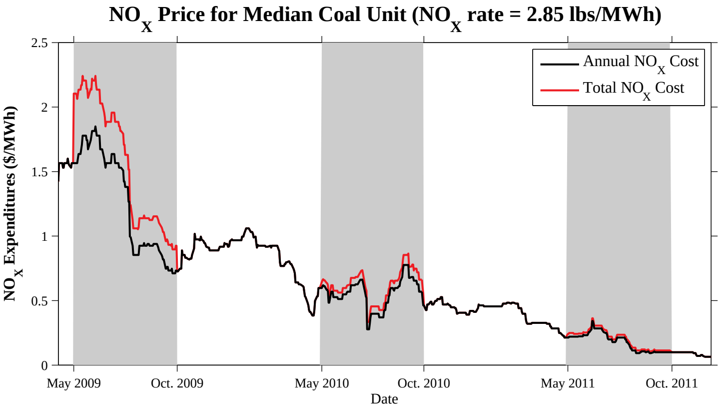
- The dispatch order is unchanged
- The input prices are unchanged (i.e. ΔNO_X price $= 0$)

NO_X Permit Prices

return

To estimate ∂(Emissions)/∂(NO_X Price)

- Need exogenous variation in NO_X Price
- My approach: exploit discontinuity caused by Ozone Season



Ozone Season Switch

return

Event study:

- 20-day window around start of Spring 2009 Ozone Season
- Estimate change in hourly Eastern Interconnection emissions (α)

$$E_t = \alpha \cdot Ozone_t + f(G_t) + \delta_{h,w} + \theta \cdot Date_t + \varepsilon_t$$

Ozone Season Switch

return

Event study:

- 20-day window around start of Spring 2009 Ozone Season
- Estimate change in hourly Eastern Interconnection emissions (α)

$$E_t = \alpha \cdot Ozone_t + f(G_t) + \delta_{h,w} + \theta \cdot Date_t + \varepsilon_t$$

E_t = Aggregate hourly NO_X (lbs), CO_2 (tons), or SO_2 (lbs)

G_t = Aggregate hourly fossil fuel generation (MWh)

$Ozone_t$ = Indicator variable for Ozone Season

Ozone Season Switch

return

Event study:

- 20-day window around start of Spring 2009 Ozone Season
- Estimate change in hourly Eastern Interconnection emissions (α)

$$E_t = \alpha \cdot Ozone_t + f(G_t) + \delta_{h,w} + \theta \cdot Date_t + \varepsilon_t$$

	NO_X (lbs)	CO_2 (tons)	SO_2 (lbs)
α	-16,809**	-2,582**	-90,629**
	(3,803)	*(735)*	*(18,754)*
N	480	480	480
R^2	0.98	0.99	0.97

Newey-West standard errors reported (72-hour lag).

** = significant at the 1% level.

Placebo Effect – Texas Interconnection

return

$$E_t = \alpha \cdot Ozone_t + f(G_t) + \delta_{h,w} + \theta \cdot Date_t + \varepsilon_t$$

$Ozone_t$ = Indicator variable for Ozone Season

E_t = Aggregate hourly TRE NO_X (lbs), CO_2 (tons), or SO_2 (lbs)

G_t = Aggregate hourly TRE fossil fuel generation (MWh)

	NO_X (lbs)	CO_2 (tons)	SO_2 (lbs)
α	11	-93	-3,004
	(543)	*(312)*	*(5,467)*
N	480	480	480
R^2	0.91	0.99	0.50

Newey-West standard errors reported (72-hour lag).

$**$ = significant at the 1% level.

Change in Generation by Technology

return

$$G_{i,t} = \alpha \cdot Ozone_t + f(G_t) + \delta_{h,w} + \theta \cdot Date_t + \varepsilon_t$$

$Ozone_t =$ Indicator variable for Ozone Season

$G_{i,t} =$ Aggregate hourly generation from fuel source i (coal, cc, gt)

$G_t =$ Aggregate hourly fossil fuel generation (MWh)

	Coal (MWh)	Combined Cycle (MWh)	Other (MWh)
α	-2,361**	2,164**	197
	(870)	*(696)*	*(1,035)*
N	480	480	480
R^2	0.99	0.98	0.97

Newey-West standard errors reported (72-hour lag).

** = significant at the 1% level.