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Overlapping Environmental Policies and the Impact on Pollution

Kevin Novan

Contributed presentation at the 60th AARES Annual Conference,
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Overlapping Environmental Policies and the Impact on Pollution

Kevin Novan

UC Davis, Agricultural and Resource Economics

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

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

Introduce a simple model of an electricity market:

- Two pollutants: one regulated, one unregulated
- ▶ Increasing renewable output can increase pollution

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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 increase
- ▶ CO_2 falls – but by much less 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

(μ_1, μ_2) = emission rates of regulated pollutant (*i.e.* NO_x)

(ρ_1, ρ_2) = emission rates of unregulated pollutant (*i.e.* CO_2)

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Demand and Renewables:

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

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Market Clearing Conditions:

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

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

Binding Emission Cap

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Increase in r or Decrease in D

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Unregulated Pollution Increases

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Positively Correlated Emission Rates:

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

And:

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

Unregulated Pollution Increases

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?

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NO_x price will fall until net $\Delta\text{NO}_x = 0$

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

With overlapping cap on a subset of pollutants:

- External benefit of renewables/conservation is small
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- “Composition Effect” doesn’t occur
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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 = Hourly fossil generation

E_t = Hourly NO_x , CO_2 , and SO_2

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Emission Rates by Technology

	Combined Cycle	Coal	Other
N	535	1,911	1,029
Median CO ₂ Rate (<i>tons/MWh</i>)	0.44	1.06	0.71
Median SO ₂ Rate (<i>lbs/MWh</i>)	0.01	6.79	0.01
Median NO _x Rate (<i>lbs/MWh</i>)	0.12	2.85	0.95

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

- Observe hourly solar capacity factors in Texas
- ▶ Capacity factor _{t} = (Generation_t) / ($\text{Installed Capacity}$)

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

(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

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- NO_x price will fall until net $\Delta \text{NO}_x = 0$
- Estimate how NO_x permit price decline impacts CO_2 and SO_2

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(2) Estimate Composition Effect

[◀ Strategy](#)

- NO_x price will fall until net $\Delta \text{NO}_x = 0$
- 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

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

E_t = Aggregate hourly NERC NO_x, CO₂, or SO₂

G_t = Aggregate hourly NERC fossil fuel generation (MWh)

Predicting the “Scale Effect” (for 2009)

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Scale effect of adding renewable capacity:

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

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Scale effect of adding renewable capacity:

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

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

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

E_t = Aggregate hourly NERC NO_x, CO₂, or SO₂

G_t = Aggregate hourly NERC fossil fuel generation (MWh)

Scale effect of adding renewable capacity:

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

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)

To estimate $\partial(\text{Emissions})/\partial(\text{NO}_x \text{ Price})$

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

Event study:

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

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

Event study:

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

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

Event study:

- 20-day window around start of Spring 2009 Ozone Season
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$$E_t = \alpha \cdot \text{Ozone}_t + f(G_t) + \delta_{h,w} + \theta \cdot \text{Date}_t + \varepsilon_t$$

	NO _x (lbs)	CO ₂ (tons)	SO ₂ (lbs)
α	-16,809** (3,803)	-2,582** (735)	-90,629** (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.

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

$Ozone_t$ = Indicator variable for Ozone Season

E_t = Aggregate hourly TRE NO_x (lbs), CO₂ (tons), or SO₂ (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.

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

$Ozone_t$ = 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** (870)	2,164** (696)	197 (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.