How Large are the Cost Savings from Emissions Trading? An Ex Post Evaluation of the Acid Rain Program

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Questions Addressed

- How do the costs of reducing SO_2 emissions under the Acid Rain Program (ARP) compare with the costs of achieving the same aggregate emissions reduction via a uniform emissions standard?
  - What were the gains from allowance trading?
  - What were the quantitative impacts of electricity market deregulation and state environmental regulation on trading gains?
- Use *observed* compliance behavior of Phase I and Phase II coal-fired generating units to estimate compliance cost functions
- Prior literature either approached this ex ante (Carlson et al., 2000) or focused on Phase I only (Arimura, 2002; Keohane, 2007)

Background of the Acid Rain Program

- The Acid Rain Program – designed to reduce SO_2 emissions by 50% from 1985 levels
- Only the most polluting units have to participate in Phase I
- $\sim$ 1100 coal-fired generating units participated in Phase II (2000–Present)
- Allowances are allocated for free at 2.5 lbs of SO_2 per MMBtu in Phase I, 1.2 lbs SO_2 per MMBtu in Phase II
- Could trade among each other (allow interstate trading) = buy allowances from others

Allowance Bank

Compliance Strategy?

There are a number of ways to comply with the Acid Rain Program:

- Use of **low sulfur coal**: transportation cost component and other chemical properties (smaller heat content) make it more expensive than other types of coal
- **Buying permits** to grant them more right to pollute
- Installing fuel-gas desulfurization units, also known as **scrubbers**
- Reducing output not a significant method of pollution control: these are baseload plants and they have to operate 24/7

My Approach

- Based on the observed compliance choice in 2002-2003 at the generating unit (boiler) level, I estimate a **discrete choice model** of whether or not to scrub and from which basin to purchase coal
  - Compliance cost, which is not observed, can be estimated from the discrete choice model
  - Only 'old' units that are not regulated by New Source Performance Standard (NSPS) are included in the estimation and simulation
- I use an iterative procedure to estimate a random coefficient logit model so that the 'cheapest' coal type is selected in each coal basin given the variation in ash and sulfur content
- Then I use the estimated model to predict their compliance choices and costs under a uniform emission standard

Previous Approaches

- Ellerman et al. (2000) looked at intertemporal gains from Phase I to Phase II based on analytical calculations on marginal abatement cost using aggregate data
- Carlson et al. (2000) estimated long-run cost function and marginal abatement cost curve based on pre-program data and shows that plants have not realized gains in Phase I. Also ignored the use of scrubbers
- Keohane (2007) focuses on scrubber installation decision (versus low sulfur coal) for Table A units, without considering other compliance strategies they can do like buying permits

Agenda

Static Model of Compliance Choice

Static over Dynamic?

- The Acid Rain Program was announced in late 1980s and it leaves plenty of time for adoption
  - Compliance choices are stable from 1995 to 2002
  - Consider choices before introduction of CAIR
- Coal prices are relative stable over the study period $\Rightarrow$ current coal prices are good proxy for future coal prices
- Similarly for Steel Mill Products Cost: Annualize capital up-front cost as per-annual operating cost

▸ Compliance Strategy ▸ Permit Prices

Static Model of Compliance Choice

- For each generating unit i, a compliance strategy is chosen to minimize fuel plus compliance cost subject to a state emission standard $\overline{SULFUR}_i$

$$\min_j C_i(j) \quad \text{s.t.} \quad (1-\theta(j))SULFUR(j) \leq \overline{SULFUR}_i \tag{1}$$

  where j indicates a scrub/coal region combination and θ is the removal rate for scrubbers

- $C_i(j)$ = Cost of coal purchase and pollution reduction (per MMBtu)
- Depends on fuel cost, cost of scrubbing, SO_2 emissions, sulfur and ash content of coal and additional retrofitting cost for burning low sulfur coal
- Coefficients interacted with state policies (incentive programs, electricity market deregulation)

Data – What do I observe?

1. **Purchase Cost of Coal**
   - FERC423 / EIA423 records almost every coal transaction
   - Information on who is buying, from where coal is bought, sulfur, ash and heat content of coal; purchase price (the minemouth price plus transportation cost) and whether the transaction is done on long-term contract
2. **Operating and Installation Cost of Scrubbers**
   - EIA-767 contains design and cost (operating and installation cost) information for each scrubber *installed*
3. **Emissions, Age and Capacity** from CEMS, EIA-860/923

Data

Problems:

- **Coal is heterogeneous in its quality.** Define coal choices as one of the six coal basins. ▸ Map of the Coal Basins
- **A plant may buy more than one type of coal.** Assign plant-level purchase to each generating unit based on observed emissions. Allow one to blend coal from two basins.
- **I have data on observed transactions only.** I imputed coal cost by running a cost regression for each coal basin (based on the averages) using all data from 1991 to 2010. Similarly for scrubbing cost.

Summary Statistics

	Mean	S.D.
Coal Cost (in cents per MMBtu)		
Illinois Basin	143.44	27.05
North Appalachian	142.23	22.17
Central Appalachian	157.59	23.28
South Appalachian	152.05	8.31
Uinta Basin	165.98	20.04
Powder River Basin	113.26	21.02
Scrub Cost (in cents per MMBtu)	39.98	24.13
Vintage	1958.59	10.22
Divested	0.2025	0.402
Deregulated	0.3389	0.4736
Heat Input (in 1000s MMBtu)	14257.23	14339.77

Random Coefficient Logit Model

I use **random coefficient logit model** to allow heterogeneous impacts of the observables which has the following log-likelihood function:

$$l(b, \Sigma) = \sum_{i=1}^{I} \ln \int_{-\infty}^{\infty} \frac{\exp(-C_i(j))}{\sum_{j'}^{J} \exp(-C_i(j'))} f(\beta | b, \Sigma) d\beta \qquad (2)$$

- Estimated by Maximum Simulated Likelihood: integral will be approximated by simulation using Halton (quasi-random) draws
- Allow β^z and β^F to be random

Random Coefficient Logit Model

- Approximating the choice by the mean sulfur and ash content may simplify the problem, but it may not able to capture the actual coal that they are buying
- Instead of attempting to expand the choice set further, I run an algorithm to predict the type of coal that they are buying based on the estimated coefficients
  - Start with a guess of β
  - For each choice j, I assume that each unit picks the coal type k_i^j that minimize the *same* compliance cost
  - Re-estimate the logit model based on attributes of k_i^j to get new β until convergence

Estimation

- Random coefficient logit model estimated using data on 785 EGUs for 2002-2003
  - Model successfully predicts around 70% of observed choices; 92% of scrubbing choices
- Dropped NSPS units from the estimation – assume that they would not change their compliance strategies
- Deregulated and divested units attached greater weight to the cost of coal and cost of scrubbing
- Estimated statistically significant retrofitting cost as well as additional operating cost associated with the use of Powder River Basin coal
- Shadow price of Permit approximately \$400/ton

Coefficients of the Cost Function

Sulfur	4.7626***	Scrub Cost	0.2876***
	(0.3763)		(0.0799)
Sulfur × Scrub	-2.8854***	Scrub Cost × Bias	-0.0113
	(0.6523)		(0.0446)
Ash	0.2167***	Scrub Cost × Restr.	0.0690
	(0.0534)		(0.0472)
Coal Cost	0.1527***	PRB	3.708***
	(0.0118)		(0.7586)
Coal Cost × In-state	-0.0096***	PRB × Age	0.0535***
	(0.0026)		(0.0140)
Coal Cost × Minemouth	-0.0476***	Modification	1.9613***
	(0.0116)		(0.1434)
Coal Cost × Restr.	0.0204**		
	(0.0087)		
Standard Deviation			
σ^F	0.0264***	σ^Z	0.1324***
	(0.0080)		(0.0481)

Counterfactual: Estimating the Cost Savings from Emissions Trading

Using estimates from my model, I proceed in the following steps to estimate the cost:

1. Back out unit-specific conditional distribution of the coefficients (Revelt and Train, 2000)

$$\mu_i(\beta|D_i = Y, X_i, b, \Sigma) = \frac{P(D_i = Y|X_i, \beta) f(\beta|b, \Sigma)}{P(D_i = Y|X_i, b, \Sigma)} \tag{3}$$

   where Y is the observed choice made by i

2. Back out the conditional mean of the logit error term which represents the unobserved using shuffled Halton Draws (Bhat, 2001). Treat them as separate unit-specific and alternative-specific constant terms.

Estimating the Cost Savings from Emissions Trading

3. Set $\beta^t = 0$ and start with a uniform emission standard $\bar{s}_{(0)}$. Find the type of coal that each unit is buying conditional on choice j such that it does not violate $\bar{s}_{(0)}$, and estimate the compliance strategy:

$$\widehat{\Pr}_i(j|X_i, b, \Sigma) = \int_{-\infty}^{\infty} \frac{\exp(-\tilde{C}_i(j))}{\sum_{j'}^{J} \exp(-\tilde{C}_i(j'))} \mu_i(\beta|X_i, b, \Sigma) d\beta \qquad (4)$$

4. Compute the aggregate compliance cost and emissions. If aggregate emissions exceed the predicted emissions in the emission trading scheme, repeat step 3 again with $\bar{s}_{(t)} = \bar{s}_{(t-1)} - 0.01$ until the emissions are close to or lower than the one before

Simulation: How Large are the Cost Savings?

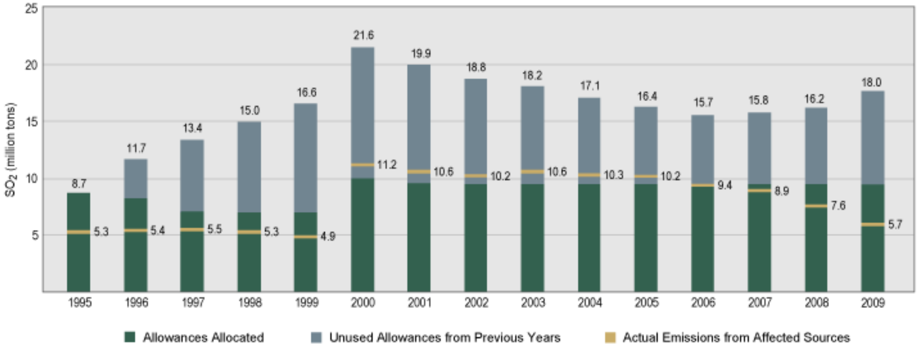
- The conditional mean of logit errors to reflect unit-specific unobserved costs associated with each choice that can be permanent

	(Average Cost Per Year, in 1995 Million USD)			
Cost	ARP	Standard	Cost Savings	
Mean Zero	1055.98	1433.10	**377.12**	**(26.31%)**
Conditional	775.25	1067.92	**292.67**	**(27.41%)**
Prior Literature				
	Carlson et al. (2000)		780	(42.87%)
	Ellerman et al. (2000)		2115	(52.39%)

Concluding Remarks

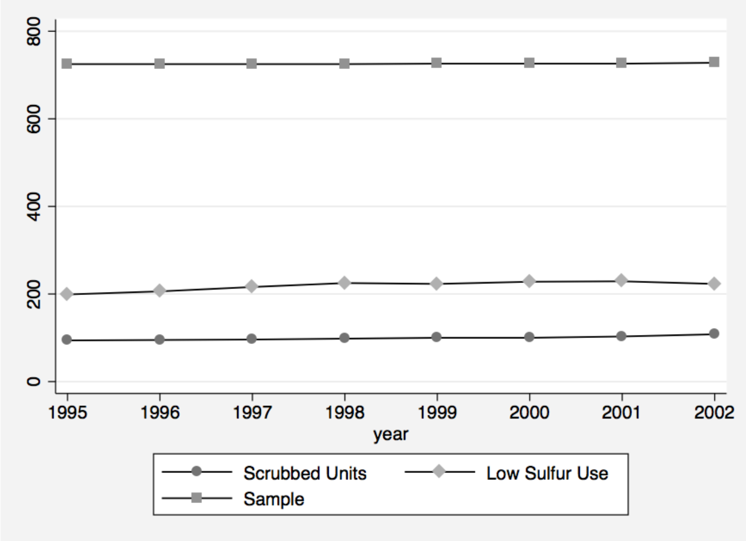
- I estimate the cost savings from market-based instruments using a choice-based approach, which extends the literature by (1) accounting for some unobserved components in operating cost, (2) using ex-post data for all units covered, and (3) jointly modeling the decision to scrub and choice of coal purchased
- My estimated cost savings are around US$290–380M per year, smaller than estimates in the 'ex-ante' literature
- In future work:
  - Correct for the bias associated with the selection issue in estimation of scrubbing cost
  - More counterfactuals on the interaction of state policies
  - Explain the difference in the estimated cost savings

Allowance Bank



Source: EPA ▸ Back

Trend in Compliance Strategy



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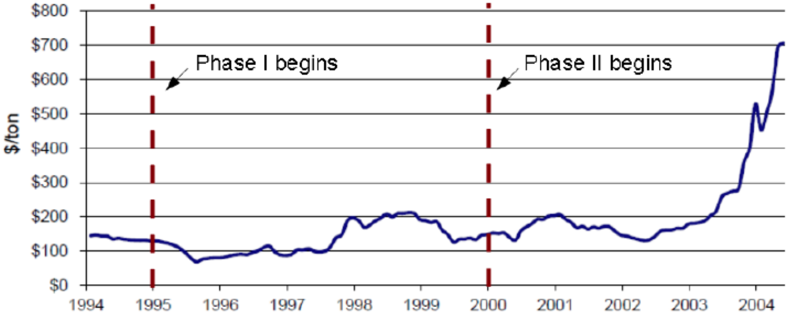
Trend in Permit Price



Source: Fraas and Richardson (2010)

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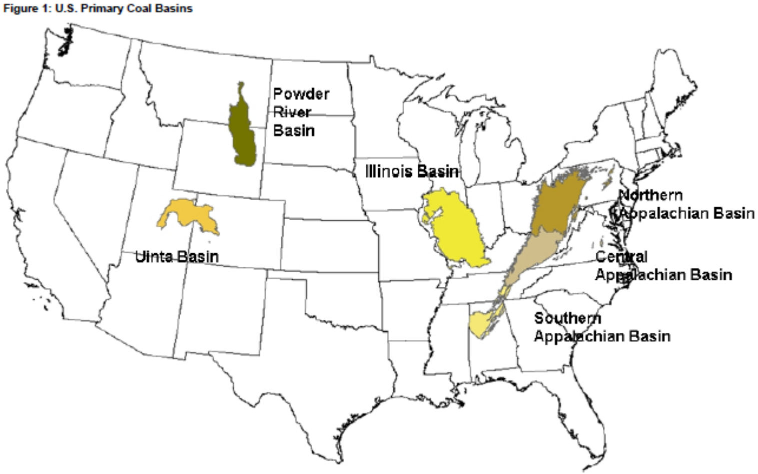
Coal Basins



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