Regulating Greenhouse Gases from Coal Power Plants Under the Clean Air Act

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Power Generation and the Environment: Choices and Economic Tradeoffs
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Background: Efficiency at Existing Coal Plants

• EPA regulation of CO₂ emissions
  • Following 2007 Supreme Court decision, EPA has begun regulating CO₂ emissions
  • Already enacted: fuel economy standards for cars and trucks
  • New source review and regulation of existing sources in development, with draft performance standards for new fossil steam units
  • Central role for performance/efficiency standards; for existing sources, apparent focus on efficiency

• How costly and how effective are efficiency standards likely to be?
  • Engineering assessments and case studies of energy efficiency suggest very low costs, whereas others are less optimistic
  • What opportunities exist—what has already been adopted?
  • How big is the rebound effect?
Operating Performance of Existing Coal Units

- Anticipating regulations for existing coal units
  - Coal accounts for about 1/3 of U.S. CO$_2$ emissions
  - Based on engineering estimates, expect 2-5 percent efficiency improvements
  - Corresponds to 1.6 percent total GHG emissions, or 10 percent of the U.S.’ 2020 target

- Costs of alternative policy designs
  - Putting aside legal issues, there are many ways to reduce emissions rates from existing coal units
  - Prominent examples: emissions cap, tradable emissions rate standard, traditional emissions rate standard
  - Each policy provides different incentives for efficiency investments and operations
Our Objectives

- Use observational data to analyze coal unit behavior
  - Construct a panel data set of coal unit operation and characteristics, 1985-2009
  - Merge in coal prices and other market and regulatory variables
  - Assess abatement opportunities based on operating efficiency (heat rates)
  - Estimate costs of reducing emissions based on historical responses of heat rates to coal prices

- Compare cost effectiveness of alternative policies
  - Use empirical estimates as inputs in a simple model of the electricity sector
  - Heterogeneity in abatement opportunities and costs treated consistently with empirical estimates
  - Compare cost effectiveness of alternative policies: emissions tax and performance standard (flexible and traditional)
Data

- **Sources:**
  - EIA 767: by boiler/generator, monthly heat input and generation, boiler vintage, firing type, and other characteristics
  - EIA 860/861: plant ownership and generator characteristics
  - EIA 423: average coal and gas prices by plant and year (new results coming soon with more complete coal prices)

- **Summary:**
  - Data are aggregated to boiler/generator unit
  - Unbalanced panel from 1985-2009
  - Final data set includes nearly all coal generators: 1250 units and 340 GW total capacity in 2008 (includes 97% of 2008 emissions)
Heterogeneity

• Annual heat input vs. average heat rate for a single year
  ▪ Units with lower heat input tend to have higher heat rates
  ▪ Lots of heat rate variation

• Distribution by firing type
  ▪ Many factors, such as firing type and pollution controls, affect heat rates but are difficult to change
  ▪ Distributions vary a lot by firing type
  ▪ Implication: some heterogeneity reflects technological differences
  ▪ Not all heterogeneity implies abatement opportunities
Figure 2: Estimated Heat Rate Distribution by Firing Type

Heat Rate (mmBtu/MWh)
Abatement Opportunities

• How much heterogeneity remains after controlling for technical factors?
  ▪ Control for whether unit is cogenerator, capacity, firing type, and fuel type
  ▪ Figure 3 shows that substantial heterogeneity remains

• Estimated opportunities for traditional emissions rate standards
  ▪ Bin units based on capacity, firing type, fuel type, cogenerator
  ▪ Impose standard for each bin based on 10th percentile of heat rate (most efficient)
  ▪ Add up emissions reductions assuming all units meet standard
  ▪ Calculation suggests 5-6% emissions reductions possible, not accounting for costs
Figure 3: Estimated Heat Rate Distribution Controlling For Technology Variables

Heat Rate (mmBtu/MWh)

- No Controls
- Control for Cogenerator, Capacity, Firing Type, Fuel Type

- After estimating costs, we compare cost effectiveness across policies
  - Using a model of coal unit behavior, we’ll simulate effects of different policies
  - Compare emissions tax, tradable emissions rate standard, traditional standard

- How do policies affect emissions?
  - Policies create incentives for firms to change heat rates and utilization
  - Example: carbon-based tax on coal raises fuel costs, which creates incentives to reduce heat rate and utilization
  - Example: tradable performance standard introduces a shadow price on heat rate proportional to fuel costs; also subsidizes output for units exceeding standard

- Cost of improving heat rate technology is a central parameter, which we estimate from the observed relationship between coal prices and heat rates
Identifying the Effect of Coal Prices on Heat Rate Technology

• Empirical challenge
  ▪ How do coal prices affect adoption of heat rate technology?
  ▪ We do not observe adoption of technologies that reduce heat rates
  ▪ Need to infer technology adoption based on observed coal prices and heat rates
  ▪ Utilization affects heat rates, but conditional on utilization, there is a direct relationship between observed heat rates and technology

• How do coal prices affect heat rates?
  ▪ Estimate simple linear regression of log heat rate on log coal price:
    \[ \ln H R_{it} = \alpha \ln P_{it} + X_{it} \beta + \epsilon_{it} \]
  ▪ Interpret \( \alpha \) as elasticity of heat rate to coal price
  ▪ Expect \( \alpha \) to be negative because high coal prices raise the benefit of improving efficiency
  ▪ Large \( \alpha \) (in magnitude) implies low cost of improving heat rate
Figure 4: Utilization, Heat Rates, and Technology
Addressing Other Empirical Concerns

• Potentially spurious results: coal prices affect utilization and therefore heat rates
  ▪ Control directly for utilization

• Unobserved unit, plant, or firm characteristics correlated with coal prices
  ▪ Example: bargaining power over coal prices
  ▪ Compare results with and without unit fixed effects
  ▪ Add firm-year interactions
## Main Estimation Results

### Effect of Coal Prices on Heat Rates

<table>
<thead>
<tr>
<th>Specification</th>
<th>Baseline</th>
<th>Add state economic controls to (1)</th>
<th>Add unit fixed effects to (1)</th>
<th>Add firm X year fixed effects to (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log Coal Price (α)</td>
<td>-0.053</td>
<td>-0.046</td>
<td>-0.016</td>
<td>-0.015</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>4,927</td>
<td>3,908</td>
<td>4,927</td>
<td>3,908</td>
</tr>
<tr>
<td>R-Squared</td>
<td>0.75</td>
<td>0.77</td>
<td>0.93</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Other control variables: age, size, firing type, fuel type, cogenerator, scrubber, SCR, utilization, state, time period, ownership type
Empirical Results

- Interpret coefficient as elasticity: 10 percent coal price increase reduces heat rates 0.2-0.5 percent

- Equivalently, $10/ton CO2 tax would reduce heat rates 1-3 percent

- The cost estimates are similar to, though perhaps smaller than, engineering-based estimates

- Find suggestive evidence on role of new source review and market incentives, which are subjects for future research
Comparing Alternative Policies

- What do empirical estimates imply for policy design?
  - Compare emissions tax with two types of standards: flexible and traditional
  - Each policy creates incentives to reduce heat rates, but standards create larger rebound effect
  - Estimate rebound effect from relationship between coal prices and utilization (results in paper)

- Simulate each policy using simple model of electricity system
  - Short-run model, assume gas is available at constant cost
  - Firms can reduce heat rates by adopting heat rate technology
  - Use first order conditions to coal unit’s profit maximization to calibrate additional parameters capturing heterogeneity
  - How do the standards affect utilization and costs of investing in new heat rate technology?
Policy Alternatives to Achieve a One Percent Emissions Reduction from Fossil Generators

<table>
<thead>
<tr>
<th></th>
<th>Traditional Standard</th>
<th>Flexible Standard</th>
<th>Coal Btu Tax</th>
<th>Emissions Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Change in Heat Rates</td>
<td>-1.00</td>
<td>-1.01</td>
<td>-0.16</td>
<td>-0.18</td>
</tr>
<tr>
<td>Percent Change in Coal Generation</td>
<td>0.19</td>
<td>0.21</td>
<td>-1.11</td>
<td>-1.09</td>
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<tr>
<td>Percent Change in Coal Emissions</td>
<td>-0.82</td>
<td>-0.81</td>
<td>-1.27</td>
<td>-1.26</td>
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<tr>
<td>Change in Investment Costs (million $)</td>
<td>709.0</td>
<td>343.0</td>
<td>50.1</td>
<td>55.1</td>
</tr>
<tr>
<td>Rebound in Emissions per Change in</td>
<td>0.13</td>
<td>0.15</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Conclusions and Future Work

• Abatement opportunities and costs
  ▪ Maximum technically feasible abatement under alternative hypothetical emissions rate standards: 5-6 percent
  ▪ Parameter estimate implies that a $10/ton CO\textsubscript{2} tax on coal would reduce heat rates by 1-3 percent
  ▪ Somewhat larger effect than engineering estimates suggest

• Comparing alternative policies
  ▪ Because of rebound effect, much lower investment costs for taxes
  ▪ Heterogeneity in abatement costs and opportunities creates advantage for flexible over traditional standard

• Future work
  ▪ Update empirical estimates using new fuel price data
  ▪ Heterogeneity in coal price coefficient? Competitiveness, firm size, …
Future Work: Haiku Simulations

- Incremental vs. large policy shocks
  - Policy scenarios under CAA regulations may require more substantial emissions rate reductions from a broader set of generators, including natural gas
  - Larger reductions may cause coal units to exit
  - Also, it’s difficult to infer benefits from reductions of other pollutants using simple dispatch model

- Incorporating results in electricity market model
  - Calibrate RFF’s Haiku electricity market model to empirical estimates of cost of reducing emissions rates
  - Consider larger emissions rate reductions over a broader range of sources for various policy scenarios
  - Estimate cost effectiveness as cost per avoided carbon dioxide emissions
  - Incorporating other work at RFF, estimate welfare effects of reducing emissions of other pollutants