Internalizing the Environmental Externalities of Power Generation in the USA:
Exploration of the Effects Using an Air Pollution Model
and a New National Grid Model
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1. Description of Our Simulation Model

2. Predicted Results of Locationally Optimized Pigouvian Emission Fees

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Why a SuperOPF Planning Tool?

Proper evaluation or optimization of electricity policies, generator investment, and transmission investment requires prediction of their system-wide, society-wide, and long-term effects.

SuperOPF Planning Tool: Some Highlights

- System-wide → Determines flows according to laws of physics
- Society-wide → Emissions, their transport, and 2a(1) PM_2.5 mortality
- Long-term → Simultaneously predicts operation, entry, and retirement

Can be used with model of any grid. We are finishing US-Canadian models. Will be publicly available and modifiable.

Transmission Lines in Our Model

5222 nodes, 8190 generators, 14225 branches
How the Model Makes Its Predictions

It finds the combination of plant construction, retirement, and operation that maximizes

   | Consumer benefits          |
   | — Annualized construction costs |
   | — Other Annual fixed costs  |
   | — Operating costs          |

over each decade, subject to meeting load and respecting network constraints.

More Detail on Features of the SuperOPF Planning Tool

• Representative hours represent joint distribution of demand, generator availability, wind, and solar
• Demand function at each node (and growth)
• “Direct current” modeling

Dataset of Existing Generators

• Capacities, heat rates, emission rates, locations, smokestack heights, marginal emission damage, etc.
• Required matching 12 datasets

How We Use Model for this Paper

• Adjust input parameters to reflect a policy
• Assume average natural gas price of $5 per million Btu
• Simulate a year, allowing generator retirement but not entry
### Assumed Costs

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Annual Total Fixed Costs ($/MW)</th>
<th>Variable Cost $/MWh (in 2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (Dual Unit Advanced PC)</td>
<td>$35,255</td>
<td>Varies</td>
</tr>
<tr>
<td>Natural Gas (Advanced NGCC)</td>
<td>$20,661</td>
<td>Varies</td>
</tr>
<tr>
<td>Natural Gas (Advanced NGCT)</td>
<td>$12,741</td>
<td>Varies</td>
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<tr>
<td>Wind</td>
<td>$10,236</td>
<td>$2</td>
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<tr>
<td>Nuclear</td>
<td>$95,571</td>
<td>$2.04</td>
</tr>
<tr>
<td>Solar</td>
<td>$5,849</td>
<td>$2</td>
</tr>
</tbody>
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### Research Question & Background

**QUESTION**

What would happen if Pigouvian Fees were applied to SO2, NOx, and CO2 emissions?

**BACKGROUND**

- SO2 and NOx transform to fine particulate matter
- Location and stack height greatly affect the Pigouvian fee per pound of SO2 and NOx
- Geographically detailed grid model therefore helps

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### CO2 Damage per Ton

- Latest US government estimate for marginal damage from CO2 is around $40 per short ton* (using a 3% discount rate)


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### Particulate Matter Air Pollution and Cardiovascular Disease: An Update From the American Heart Association

*Circulation, Volume 121(21):2331-2378 June 1, 2010*

"Exposure to PM <2.5 μm in diameter (PM2.5) over a few hours to weeks can trigger cardiovascular disease–related mortality..."
Converting NO\textsubscript{X} and SO\textsubscript{2} Into Estimated Mortality Cost

- Seventy million county-to-county transfer coefficients
- Population per county, and percentage over 30
- Dose-response functions
- $7.4$ per premature death

2. POLICY EVALUATION RESULTS

Premature Deaths per Year from Power Plant Emissions Under 4 Policies

Percent CO\textsubscript{2} Reductions in the Eastern Interconnection Under 3 Policies
Annual Costs to Society of Electricity Under Four Policies

Why Is NO\textsubscript{X} & SO\textsubscript{2} Fee More Effective than CO\textsubscript{2} Fee?

- Marginal NO\textsubscript{X} and SO\textsubscript{2} damage per MWh is more heterogeneous than is CO\textsubscript{2} damage per MWh and/or
- Marginal NO\textsubscript{X} and SO\textsubscript{2} damage per MWh is less correlated with marginal direct cost than is CO\textsubscript{2} damage per MWh

Retail Electricity Price Under Four Policies

Summary of Results

- If marginal damages are only charged for CO\textsubscript{2}, there is a 20% reduction in CO\textsubscript{2} but, surprisingly, program costs can be justified by lives saved alone. Retail prices go up by around 3 cents per kilowatt-hour.
- If marginal damages are only charged for health effects, CO\textsubscript{2} is also reduced by 20% and 7000 lives are saved each year with a smaller increase in electricity prices of around 2 cents per kilowatt-hour.
- If marginal damages are charged for both health effects and CO\textsubscript{2}, there is a 30% reduction in CO\textsubscript{2} and around 8,000 lives are saved each year. Average retail rates go up by about 5 cents per kilowatt-hour.