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

Joshua Linn (RFF)
Dallas Burtraw (RFF)
Erin Mastrangelo (Maryland)

Power Generation and the Environment: Choices and Economic Tradeoffs

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Background: Efficiency at Existing Coal Plants

- EPA regulation of CO_2 emissions
  - Following 2007 Supreme Court decision, EPA has begun regulating CO_2 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 1: Heat Input vs. Heat Rate (2008)

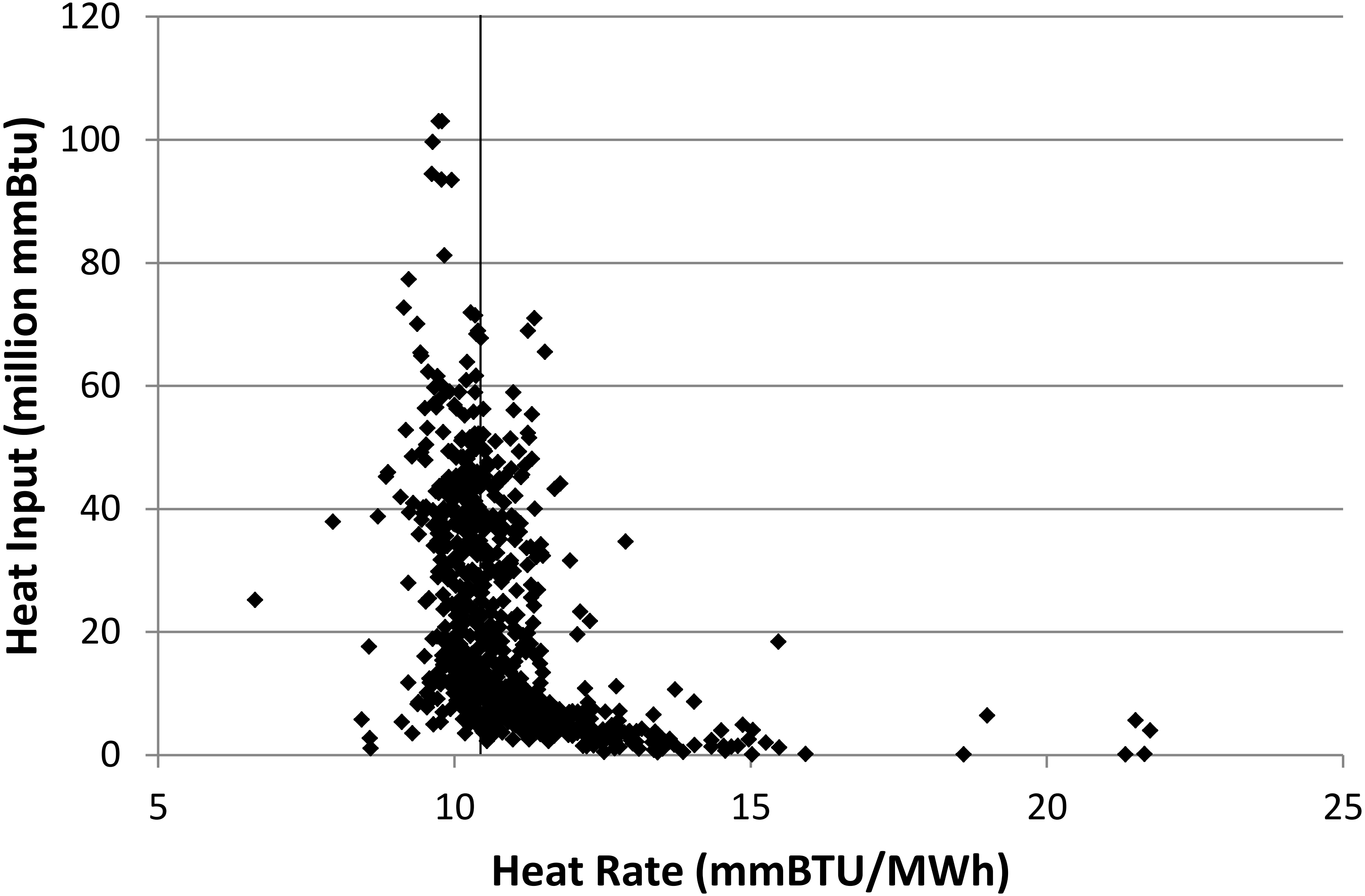

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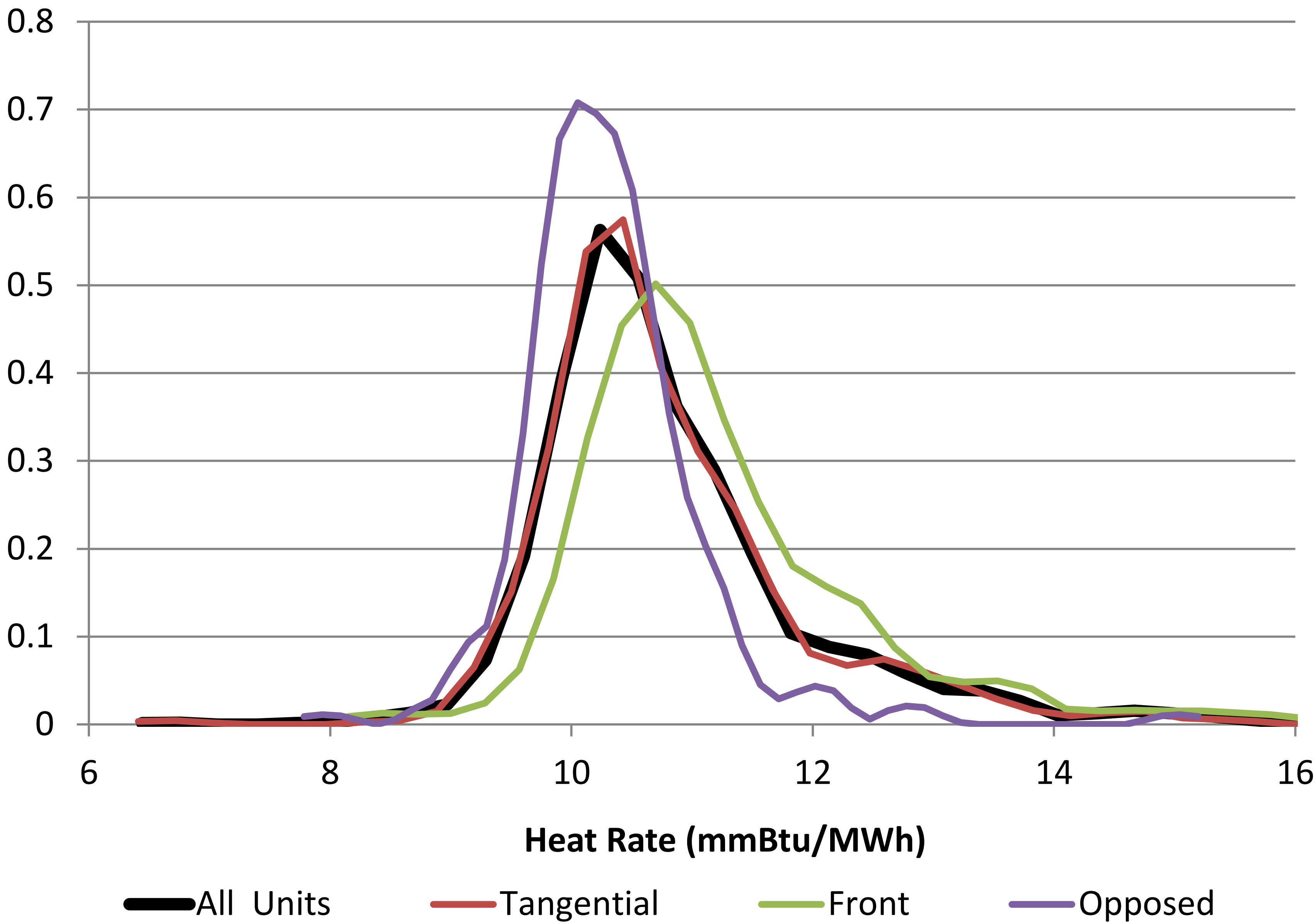
Figure 2: Estimated Heat Rate Distribution by Firing Type

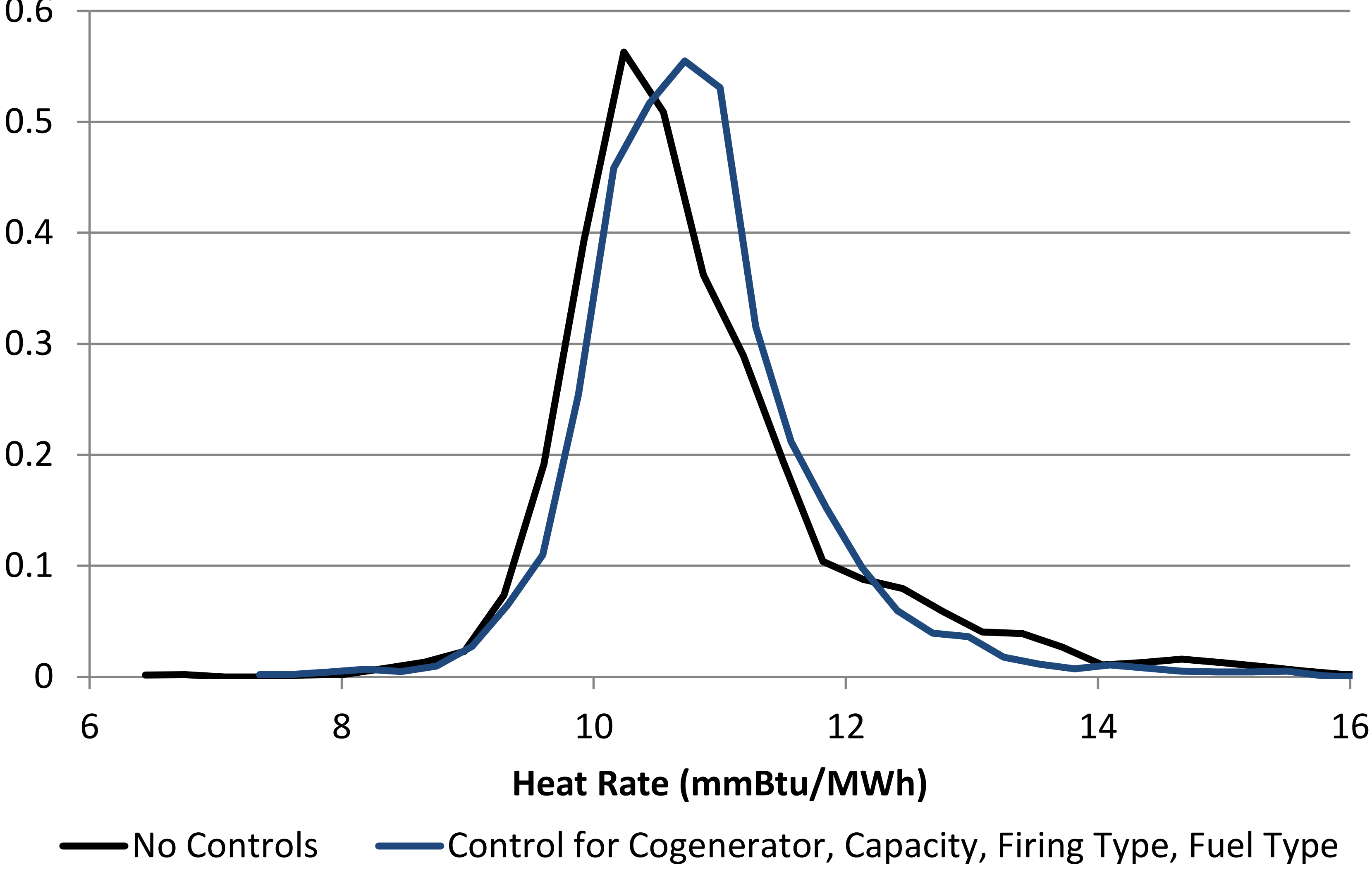


Abatement Opportunities

- 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 10^{th} 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



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Framework for Estimating Abatement Costs and Assessing Policies

- 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:

$$lnHR_{it} = \alpha lnP_{it} + X_{it}\beta + \epsilon_{it}$$

  - Interpret α as elasticity of heat rate to coal price
  - Expect α to be negative because high coal prices raise the benefit of improving efficiency
  - Large α (in magnitude) implies low cost of improving heat rate

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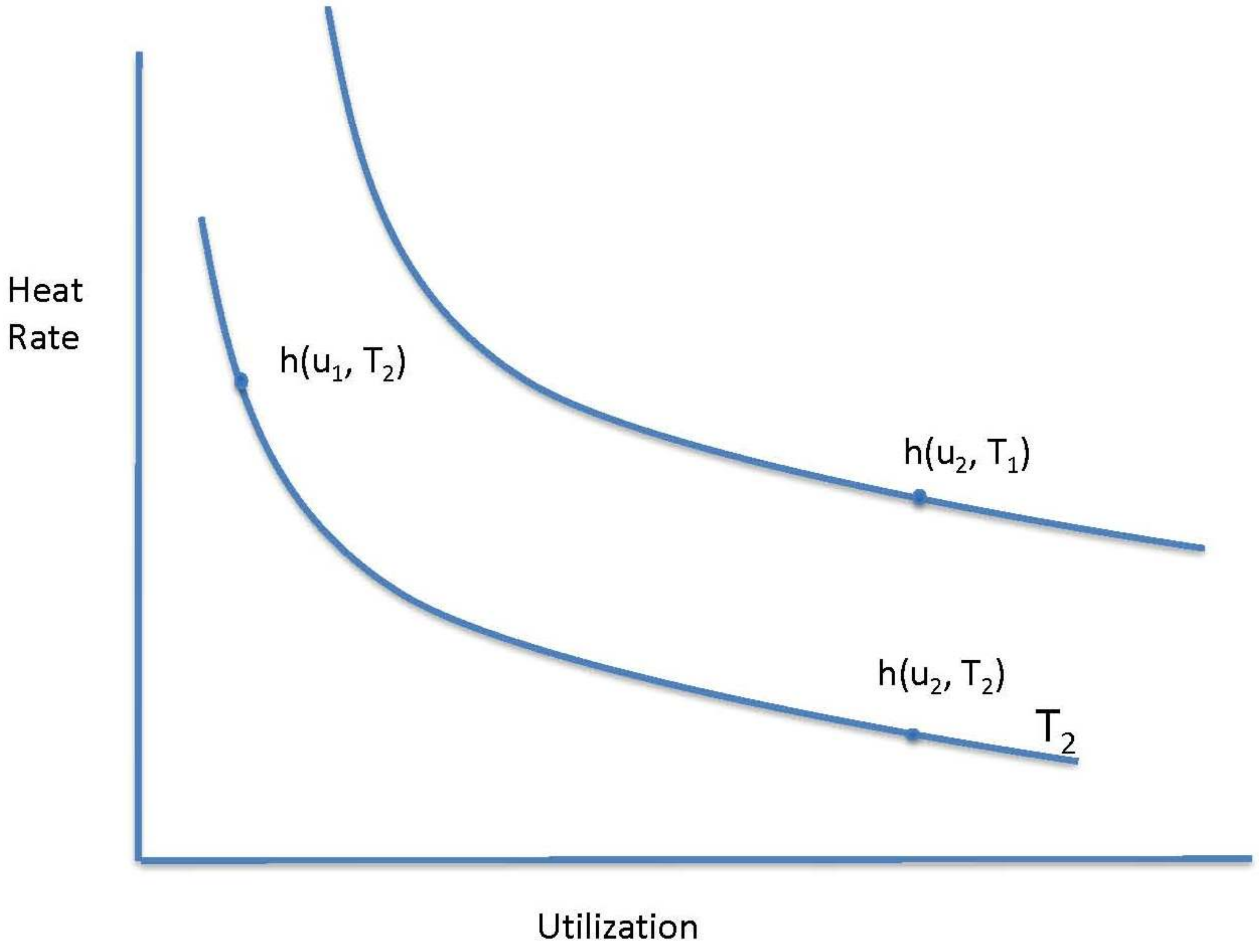
Figure 4: Utilization, Heat Rates, and Technology



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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

	Dependent Variable: Log Heat Rate			
	(1)	(2)	(3)	(4)
Log Coal Price (α)	-0.053 (0.008)	-0.046 (0.008)	-0.016 (0.009)	-0.015 (0.009)
Number of Observations	4,927	3,908	4,927	3,908
R-Squared	0.75	0.77	0.93	0.94
Specification	Baseline	Add state economic controls to (1)	Add unit fixed effects to (1)	Add firm X year fixed effects to (3)

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

	Traditional Standard	Flexible Standard	Coal Btu Tax	Emissions Tax
Percent Change in Heat Rates	-1.00	-1.01	-0.16	-0.18
Percent Change in Coal Generation	0.19	0.21	-1.11	-1.09
Percent Change in Coal Emissions	-0.82	-0.81	-1.27	-1.26
Change in Investment Costs (million $)	709.0	343.0	50.1	55.1
Rebound in Emissions per Change in	0.13	0.15	0.02	0.02

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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_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, …

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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