Fuel Switching from Coal to Gas: The Impact of Coal Stockpiling at U.S. Coal-fired Plants

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Motivation

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- Notice of Proposed Rulemaking (NOPR)
  - Power plants that have a 90-day fuel stockpile would be eligible for "full recovery of costs"
  - To preserve the diversity of the fuel mix

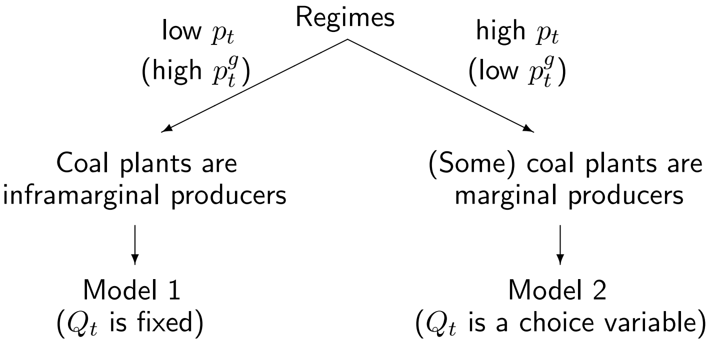
Contribution

- Coal generation, fuel switching, and GHG emissions respond to fuel costs
  - Nonlinear impact of the relative fuel prices (Cullen and Mansur, 2015)
  - Natural experiment for a carbon tax (Lu et al., 2012)
  - Marginal emissions rate (Holladay and LaRiviere, 2015)
  - Renewable energy (Fell and Kaffine, 2017)
- Inventory management impacts operation decision
  - Chen et al. (2013); Hall and Rust (2007); Scarf (1959); Jha (2014)
- The interaction effect is missing

Outline

- Theoretical model
  - Min-take contracts and coal storage constraints reduce the sensitivity of power plants to changes in relative input prices
- Empirical analysis
  - Coal plants are less responsive to fuel price fluctuations when coal stockpile levels are higher
- Counterfactual experiment
  - 18% larger impacts of a $20 carbon tax if no such effects of stockpiling

Conceptual Model



- Extended period of high p_t leads to higher coal stockpiles
- Fuel price elasticity of coal generation is smaller when coal storage constraint is binding

Data

- Form EIA-906 (2002–2007) and EIA-923 (2008–2012)
  - Monthly plant-level data
  - Coal stockpiles, capacity, generation, etc.
- Form FERC-423 (2002–2007) and EIA-923 (2008–2012)
  - Order-level data, aggregated to monthly plant-level
  - Fuel prices
- 325 Utility-owned coal plants are examined (31,855 observations)

Summary Statistics

stats	(1) p^c/p^g	(2) Coal Stockpile	(3) Coal stockpile, deviation from MOY avg.	(4) Coal-fired generation	(5) Generation capacity
		(1,000 metric tons)		(GWh)	(MW)
Panel A: The whole period (2002–2012)					
mean	0.42	416.83	12.28	426.81	975.84
sd	0.26	437.78	232.47	400.47	764.33
Panel B: Period 1 (2002–2008)					
mean	0.28	354.64	-37.55	440.67	933.38
sd	0.11	363.88	185.11	410.91	767.08
Panel C: Period 2 (2009–2012)					
mean	0.64	513.41	89.67	405.27	1041.78
sd	0.27	518.04	273.71	382.73	755.39

Econometric Model

$$
\begin{aligned}
\log Q_{it} = & \beta_0 + \boldsymbol{\beta_1 g}(\log p_{it}, \log z_{i,t-1}) + \beta_2 \log Cap_{it} \\
& + \theta_i + \eta_m + \xi_y + \mu_{NERC,m} + \nu_{it}
\end{aligned}
$$

where

- p_{it}: relative fuel costs (p_{it}^c / p_{it}^g)
- $z_{i,t-1}$: a measure of coal stockpile at the beginning of month
- Cap_{it}: generation capacity
- θ_i, η_m, ξ_y and $\mu_{NERC,m}$: Fixed effects

Policy Variable

$z_{i,t-1}$: policy variable. A measure of coal stockpiles

- A: Coal stockpile levels
- B: 'A' minus plant-level MOY average stockpile levels
- C: Binning

Model Specifications

- Model A (Coal stockpile levels)

$$\begin{aligned}\boldsymbol{\beta_1 g}(\cdot) =& \beta_{11} \log p_{it} \log z_{i,t-1} + \beta_{12} \log p_{it} (\log z_{i,t-1})^2 \\ &+ \beta_{13} (\log p_{it})^2 \log z_{i,t-1} + \beta_{14} (\log p_{it})^2 (\log z_{i,t-1})^2 \\ &+ \beta_{15} \log p_{it} + \beta_{16} (\log p_{it})^2 \\ &+ \beta_{17} \log z_{i,t-1} + \beta_{18} (\log z_{i,t-1})^2.\end{aligned}$$

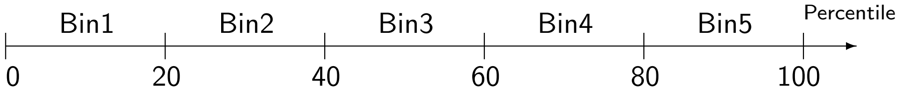
- Model B (deviation from within-plant MOY average)

$$\begin{aligned}\boldsymbol{\beta_1 \tilde{g}}(\cdot) =& \boldsymbol{\beta_1^+} \left[\mathbb{I}(z_{i,t-1} > 0) \times \boldsymbol{g}(\log p_{it}, \log z_{i,t-1})\right] \\ &+ \boldsymbol{\beta_1^-} \left[\mathbb{I}(z_{i,t-1} \leq 0) \times \boldsymbol{g}(\log p_{it}, \log(-z_{i,t-1}))\right]\end{aligned}$$

Model Specifications (continued)

- Model C (Binning)

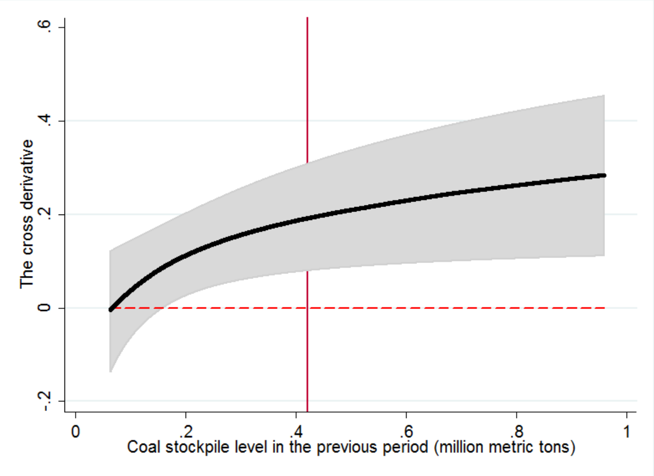
$$
\begin{aligned}
\log Q_{it} = \beta_0 &+ \sum_{j=1}^{5} \beta_{1,j} BIN_{j,t-1} \log p_{it} + \sum_{j=1}^{5} \beta_{2,j} BIN_{j,t-1} (\log p_{it})^2 \\
&+ \sum_{j=1}^{5} \beta_3 BIN_{j,t-1} + \beta_4 \log Cap_{it} \\
&+ \theta_i + \eta_m + \xi_y + \mu_{NERC,m} + \nu_{it}.
\end{aligned}
$$



Hypothesis

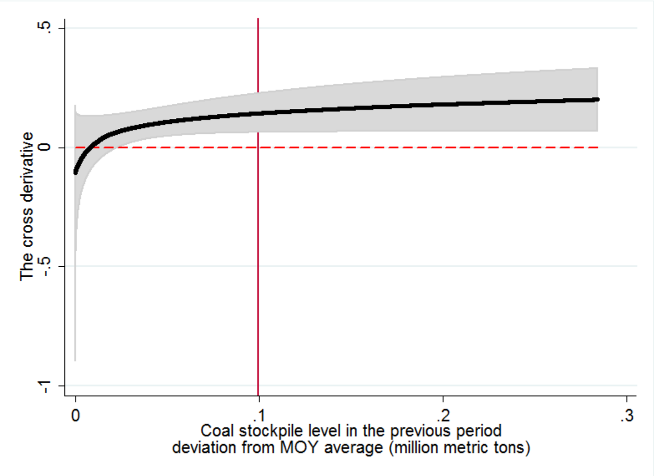
- Argument
  - Fuel price elasticity of coal-based generation is decreasing in z
- Null hypothesis
  - $\left|\frac{\partial \log Q_{it}}{\partial \log p_{it}}\right|$ is non-decreasing in z
  - $\frac{\partial \log Q_{it}}{\partial \log p_{it}}$ is non-increasing in z
  - $$H_0 : \frac{\partial^2 \log Q_{it}}{\partial \log p_{it} \partial \log z_{i,t-1}} \leq 0$$
    $$H_A : \frac{\partial^2 \log Q_{it}}{\partial \log p_{it} \partial \log z_{i,t-1}} > 0$$

Results: Model A



▸ With demand controlled

Results: Model B



▸ With demand controlled

Results: Model C

$$\epsilon_j = |\partial \log Q_{it} / \partial \log p_{it}|_j = |\beta_{1,j} + 2\beta_{2,j} \log p_{it}|$$

Null hypothesis	(1)	(2)	(3)	(4)	(5)
$H_0 : \epsilon_1 - \epsilon_5 \leq 0$	-0.0323	-0.0345	-0.0366	-0.0367	-0.0367
	(0.101)	(0.097)	(0.098)	(0.122)	(0.090)
$H_0 : \epsilon_2 - \epsilon_5 \leq 0$	0.1581	0.1401	0.1379	0.1379	0.1379*
	(0.111)	(0.106)	(0.106)	(0.122)	(0.073)
$H_0 : \epsilon_3 - \epsilon_5 \leq 0$	0.1850*	0.1595*	0.1579*	0.1579	0.1579***
	(0.096)	(0.094)	(0.093)	(0.122)	(0.041)
$H_0 : \epsilon_4 - \epsilon_5 \leq 0$	0.0094	-0.0043	-0.0031	-0.0031	-0.0031
	(0.079)	(0.077)	(0.077)	(0.078)	(0.035)
Time FE	N	Y	Y	Y	Y
Nerc × month FE	N	N	Y	Y	Y
Standard errors clustered at	Plant-level	Plant-level	Plant-level	State-level	NERC-level

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Counterfactual Experiment

- Carbon tax drives up relative fuel costs
- Then we would expect coal stockpiling to hinder fuel price elasticity of coal-based generation
- $\Delta E = CI\left(\frac{ton}{MMBtu}\right) \cdot HR\left(\frac{Btu}{kWh}\right) \cdot 10^{-6}\left(\frac{MMBtu}{Btu}\right) \cdot \Delta Q\ (kWh)$
- $\Delta E = |\Delta E^{coal}| - |\Delta E^{gas}|$
- Results
  - $\Delta E = 55\mathrm{MMTCO_2E}$ (3.34% reduction) in the benchmark
  - $\Delta E = 65\mathrm{MMTCO_2E}$ (3.95% reduction) in the counterfactual
  - 18.18 percent larger carbon abatement without binding coal storage constraint

Conclusion

- Coal stockpiling and the min-take contracts are important components in forecasting the fuel mix when relative fuel prices change
- Without binding coal storage constraint, we would have observed larger degree of fuel switching from coal to gas

Questions?

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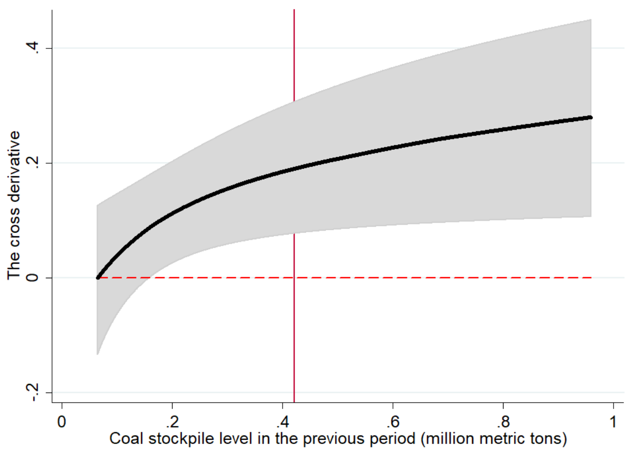
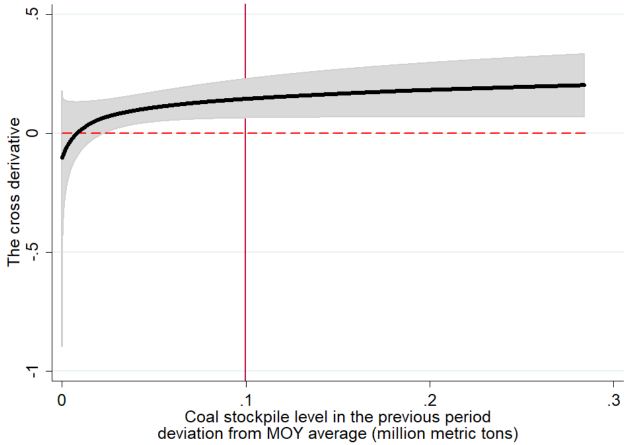

The cross derivative
-.2
0
.2
.4
0
.2
.4
.6
.8
1
Coal stockpile level in the previous period (million metric tons)

Go back


.5
0
-.5
-1
The cross derivative
0
.1
.2
.3
Coal stockpile level in the previous period
deviation from MOY average (million metric tons)

Go back

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