Still your grandfather's boiler

Estimating the effects of the Clean Air Act's grandfathering provisions

Sylwia Bialek,[1,2] Jack Gregory,[3] Bridget Pals & Richard L. Revesz[1]

AERE@OSWEET

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[1] Institute for Policy Integrity, NYU
[2] German Council of Economic Experts
[3] University of California, Davis

Vintage Differentiation I

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- **Grandfathering** $\longrightarrow$ form of vintage differentiation where existing units are completely exempted from the regulation.
- Some examples:
  - US Clean Air Act & Clean Water Act
  - Emission trading scheme permits
  - Building codes & zoning laws
  - Underground storage tanks
  - Landfill regulation

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  - Extending the lifetime of incumbent units $\longrightarrow$ decreasing new entry.
  - Decreasing the relative marginal costs of incumbent units $\longrightarrow$ influencing their operation and that of regulated units.
- Nevertheless, *vintage differentiation is not well understood.*

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- Study the impacts of 1977 Clean Air Act (CAA) New Source Review (NSR) grandfathering provisions on damages from coal boiler sulfur emissions.
- Estimate the response to grandfathering provisions through three dimensions:
  - Utilization (intensive margin);
  - Survival (extensive margin); and,
  - Emissions intensity.

Literature

Preview of results

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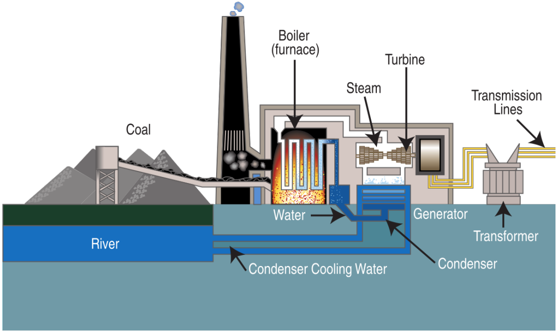
2. Stringent state and other federal regulations, reduce new source bias.
3. Damages are large but decrease over time.

New Source Review

- **Legislation**
  - Part of the 1977 CAA Amendments.
  - Required 90% SO_2 emission abatement, but gave exemptions for existing boilers.
  - 1978 – Utility boilers above 70 MW.
  - 1984 – Commercial and industrial boilers above 10 MW.
  - 1989 – Commercial and industrial boilers above 1 MW.



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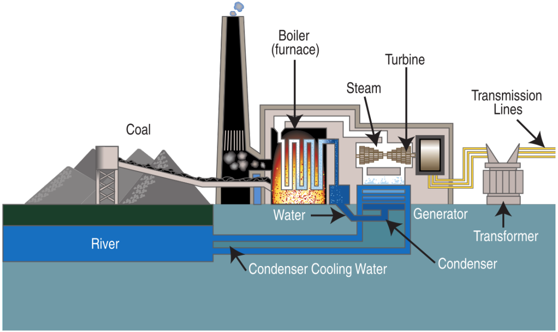

- **Outcome**
  - Effectively imposed a costly technology requirement (i.e., scrubber).

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- Relevant for both the extensive and intensive margins of boiler operation.
- NSR may interact with other sulfur regulations, including:
  - National Ambient Air Quality Standards (NAAQS)
  - New Source Performance Standards (NSPS)
  - Acid Rain Program, Clean Air Interstate Rule, and Cross-State Air Pollution Rule
  - State regulations

Data

- Environmental Protection Agency
  - CEMS ⟶ hours of operation and emissions by boiler
  - Green Book ⟶ attainment status
  - Sulfur allowance prices
- Energy Information Agency
  - Forms 767, 860, 861, 923 and precursors ⟶ boiler characteristics, sulfur content of coal, electricity demand by state
- State Implementation Plans
  - Local sulfur regulations
- Federal Register
  - Assignment to Acid Rain Program
- EIA 767, company calls and heuristics ⟶ grandfathering status Map

Conceptual Framework

Decomposition of NSR grandfathering effects

- Use emissions identity help us think through the effects of grandfathering status.[4]
- Differentiating wrt to grandfathering status results in the three dimensions:

$$\Delta E = \left(\frac{\mathrm{d}h_0}{\mathrm{d}GF} N_0 + \frac{\mathrm{d}N_0}{\mathrm{d}GF} h_0\right) \cdot (I_0 - I_1) \quad + \quad H_0 \cdot \frac{\mathrm{d}I_0}{\mathrm{d}GF} \tag{1}$$

Emissions Identity

[4] We assume the share of generation from coal is not responsive to grandfathering status changes, such that estimates can be interpreted as a lower bound.

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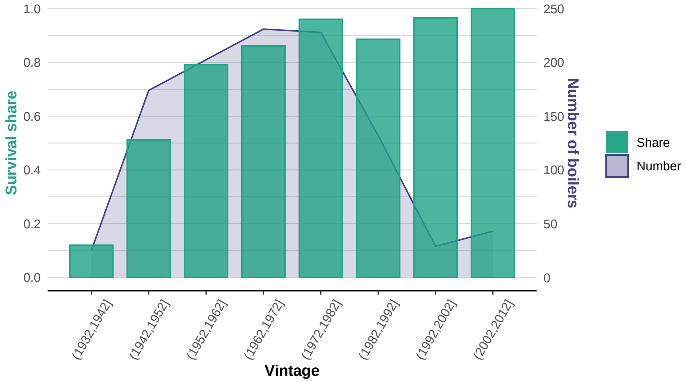
Figure: Propensity to survive until 2014 for boilers from different vintages



Boiler Replacement Decision

- We compare the profits of a new boiler with those of an existing one i with owner type m, located in region j during year t, which yields the replacement probability:

$$
\begin{aligned}
y_{it} = & \beta_1 GF_{it} + \beta_2 NAAQS_{jt} + \beta_3 NAAQS_{jt} \cdot GF_{it} \\
& + \beta_4 MMBTU_{it} + \beta_5 MMBTU_{it} \cdot GF_{it} \\
& + \beta_6 size_i + \beta_7 size_i \cdot GF_{it} \\
& + \beta_8 price_{it} + \beta_9 \widehat{SO2cont}_{it} + \beta_{10} price_{it} \cdot \widehat{SO2cont}_{it} \\
& + \mathbf{X}_{it}^{y} \boldsymbol{\Gamma}_{x}^{y} + \mathbf{Z}_{jt}^{y} \boldsymbol{\Gamma}_{z}^{y} + \alpha_j + \mu_m + \eta_t + \varepsilon_{it},
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- We use similar specifications for utilization and emissions intensity.

Threats to Inference

Regression Results[5]

	(1) **Utilization** *IV*	(2) **Survival** *IV*	(3) **Emissions** *IV*
GF	2531.18***	3.24**	3.90***
	(9.62)	(3.28)	(8.84)
size	3019.03***	2.76*	0.52
	(7.60)	(2.00)	(0.76)
GF × size	−1935.51***	−2.01	−2.78***
	(−5.63)	(−1.47)	(−4.17)
NAAQS	1080.34***	3.96***	2.13***
	(5.32)	(3.70)	(4.60)
GF × NAAQS	−1900.87***	−4.94***	−2.79***
	(−7.65)	(−3.42)	(−5.68)
MMBTU	44.66	0.24	−0.06
	(0.84)	(0.86)	(−0.36)
GF × MMBTU	−385.66***	−0.95***	−0.98***
	(−6.63)	(−3.09)	(−5.62)
Observations	10,436	12,626	10,227
R^2	0.300	0.107	0.440

Utilization | Survival | Emissions

All regressions use 2SLS with the sulfur content IV as well as year, state and owner-type fixed effects and market and sulfur controls. The unit of observation is boiler-year, while the sample is restricted to commercial, industrial and IOU boilers. Utilization and emissions use data between 1995 and 2018, while survival uses between 1985 to 2017. We use robust standard errors. *t*-statistics are in parentheses. Significance: *** $p<0.001$; ** $p<0.01$; * $p<0.05$.

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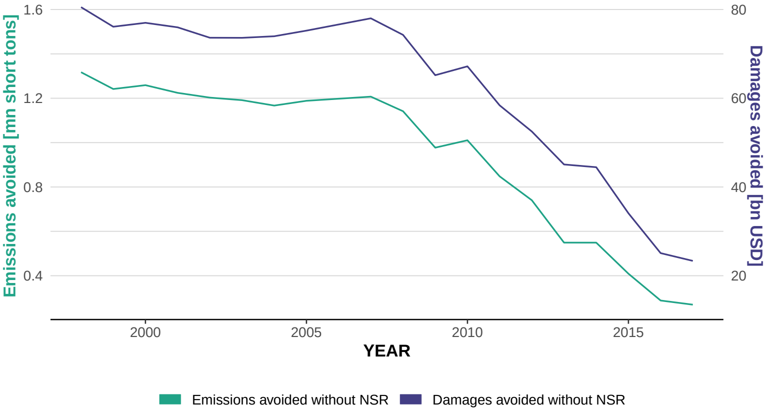
Emissions & Damages

Figure: Total SO_2 emissions and damage effects from NSR



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- Other federal programs as well as local regulations help mitigate these perverse effects.
- Damages were substantial, but decreased over time with the introduction of additional regulations.

Thank You!

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jack@ucdavis.edu

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Appendices

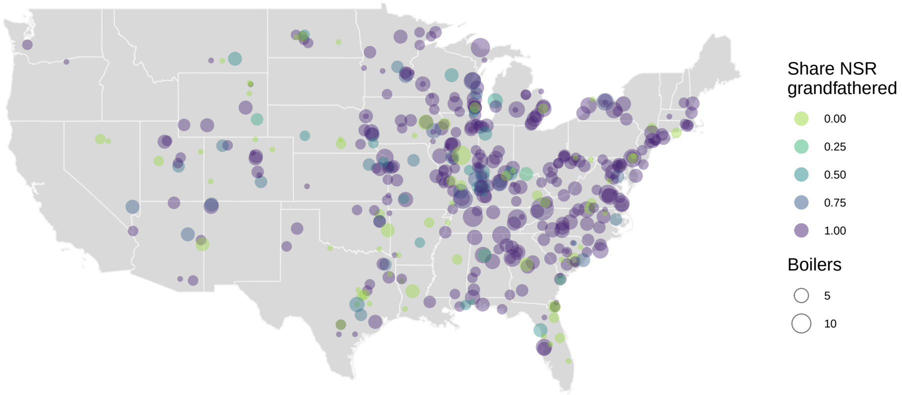
Literature

- Legal studies on the rationale for vintage differentiation
  (e.g., Stavins, 2006; Nash and Revesz, 2007; Revesz and Westfahl Kong, 2011; Serkin and Vandenbergh, 2018)
- Economic theory behind vintage differentiation
  (e.g., Böhringer and Lange, 2005; Anderson et al., 2011; Damon et al., 2019)
- Effects of vintage differentiation in CAA simulations
  (e.g., Ackerman et al., 1999; Cohan and Douglass, 2011)
- Empirical studies
  - Effects congruent with vintage differentiation theory
    (e.g., Nelson et al., 1993; Bialek and Weichenrieder, 2021)
  - Cross-country estimates
    (e.g., Coysh et al., 2020)
  - Related to the CAA
    (e.g., Lange and Linn, 2008; Keohane et al., 2009; Heutel, 2011; Bushnell and Wolfram, 2012; Raff and Walter, 2020)

Return

Grandfathering Status

Figure: Coal-fired boilers by initial NSR grandfathering status



Sulfur Content

- Sulfur content instrumental variable
  - Weighted average of the median sulfur content of coal from all counties using their inverse distances to the plant as weights.

Figure: Median sulfur content of coal by county

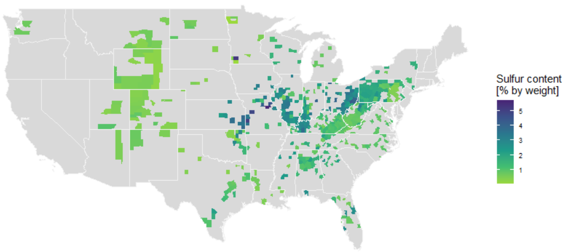
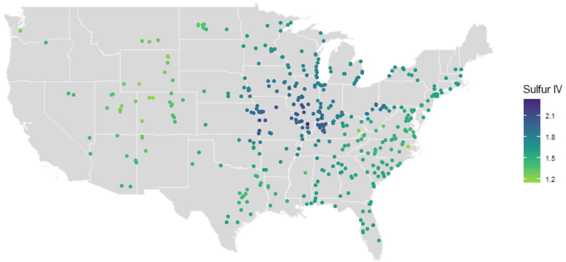


Figure: Sulfur content of available coal by plant



Return

Emissions Identity

- Identity for coal boiler emissions, E:

$$\begin{aligned} E &= E_0 + E_1 \\ &= H_0 \cdot I_0 + (H - H_0) \cdot I_1 \\ &= h_0 \cdot N_0(I_0 - I_1) + H \cdot I_1 \end{aligned} \tag{3}$$

  - $i \longrightarrow$ boiler type as either incumbent 0 or new 1
  - $E_i \longrightarrow$ emissions of type i
  - $H_i \longrightarrow$ total average number of hours in operation for type i
  - $I_i \longrightarrow$ average emission intensity for type i
  - $N_i \longrightarrow$ number of boilers of type i
  - $h_i \longrightarrow$ average number of hours an individual boiler operates annually for type i

Main Threats to Inference

- **Endogeneity of grandfathering status**: bunching behavior & modification clause
  - Bunching relatively unlikely.
  - Modification clause hardly enforced until end of 1990s, leading to 20% rule in 2000s.
  - Use only initial assignment to grandfathering status.
- **Systematic differences** between grandfathered and non-grandfathered units
  - Differences in timing of NSR introduction for boilers run by: utilities; commercial and industrial owners; and, for small commercial and industrial boilers.
  - Size thresholds for NSR applicability.
  - ~~Matching~~

Return

Utilization Regressions

	(1) OLS IOU+	(2) OLS IOU+	(3) OLS IOU+	(4) OLS IOU+	(5) IV IOU+	(6) IV All	(7) IV IOU
GF	832.50***	2445.11***	2568.51***	2533.83***	2531.18***	1357.56***	2606.32***
	(13.36)	(9.62)	(9.81)	(9.10)	(9.62)	(7.32)	(7.06)
size	1288.69***	3102.65***	3166.51***	3314.39***	3019.03***	2054.01***	2930.57***
	(9.74)	(8.76)	(8.64)	(8.38)	(7.60)	(8.15)	(5.50)
GF × size		−1933.86***	−2070.97***	−2298.18***	−1935.51***	−658.19**	−1908.99***
		(−5.74)	(−5.95)	(−6.18)	(−5.63)	(−2.63)	(−3.87)
NAAQS		1066.37***	1088.42***	1185.16***	1080.34***	1006.74***	1138.10***
		(6.82)	(6.22)	(6.51)	(5.32)	(5.32)	(5.21)
GF × NAAQS		−1811.97***	−1879.89***	−1543.99***	−1900.87***	−1805.99***	−2051.80***
		(−9.38)	(−8.82)	(−7.25)	(−7.65)	(−8.52)	(−8.36)
MMBTU		37.56	38.54	27.49	44.66	159.35***	51.17
		(0.77)	(0.79)	(0.58)	(0.84)	(3.37)	(0.94)
GF × MMBTU		−380.89***	−386.14***	−285.16***	−385.66***	−465.71***	−400.97***
		(−6.81)	(−6.89)	(−6.34)	(−6.63)	(−9.52)	(−5.88)
Year FE	X	X	X	X	X	X	X
State FE	X	X	X	X	X	X	X
Utility FE	X	X	X	X	X	X	
Market Controls			X	X	X	X	X
Sulfur Controls				X	X	X	X
Observations	10,782	10,782	10,436	9,762	10,436	16,291	9,927
R^2	0.289	0.303	0.300	0.294	0.300	0.295	0.288

Return

Survival Regressions

	(1) OLS IOU+	(2) OLS IOU+	(3) OLS IOU+	(4) OLS IOU+	(5) IV IOU+	(6) IV All	(7) IV IOU
GF	0.86**	2.88**	3.31***	2.63**	3.24**	2.24**	4.25**
	(3.02)	(3.17)	(3.32)	(2.78)	(3.28)	(3.20)	(3.19)
size	0.63	2.70*	3.21*	2.79*	2.76*	1.55	3.88*
	(1.16)	(2.30)	(2.50)	(2.17)	(2.00)	(1.93)	(1.96)
GF × size		−2.29	−2.38	−1.97	−2.01	0.01	−3.19
		(−1.96)	(−1.86)	(−1.59)	(−1.47)	(0.01)	(−1.82)
NAAQS		2.87**	3.94***	2.99**	3.96***	3.71***	4.22***
		(2.98)	(3.31)	(2.88)	(3.70)	(3.94)	(3.29)
GF × NAAQS		−4.03***	−4.85**	−5.14***	−4.94***	−5.00***	−5.23***
		(−3.50)	(−3.24)	(−3.57)	(−3.42)	(−4.34)	(−3.42)
MMBTU		0.14	0.22	−0.31*	0.24	0.10	0.39
		(0.56)	(0.76)	(−2.15)	(0.86)	(0.56)	(1.47)
GF × MMBTU		−0.52**	−0.66**	−0.25	−0.66**	−0.73**	−0.81**
		(−2.91)	(−2.99)	(−1.66)	(−3.09)	(−2.62)	(−3.20)
Year FE	X	X	X	X	X	X	X
State FE	X	X	X	X	X	X	X
Utility FE	X	X	X	X	X	X	
Market Controls			X	X	X	X	X
Sulfur Controls				X	X	X	X
Observations	15,257	15,257	12,626	11,738	12,626	19,125	11,694
R^2	0.101	0.102	0.107	0.103	0.107	0.099	0.109

Return

Emissions Regressions

	(1) OLS IOU+	(2) OLS IOU+	(3) OLS IOU+	(4) OLS IOU+	(5) IV IOU+	(6) IV All	(7) IV IOU
GF	0.55***	4.60***	4.60***	4.73***	3.90***	3.43***	4.13***
	(4.19)	(12.31)	(12.31)	(12.54)	(8.84)	(11.27)	(9.86)
size	−2.00***	2.57***	2.57***	2.82***	0.52	−0.47	0.68
	(−9.19)	(6.53)	(6.53)	(7.27)	(0.76)	(−1.29)	(1.09)
GF × size		−4.66***	−4.66***	−4.87***	−2.78***	−2.60***	−3.08***
		(−10.73)	(−10.73)	(−11.35)	(−4.17)	(−6.10)	(−5.10)
NAAQS		2.39***	2.39***	1.51***	2.13***	1.73***	2.17***
		(5.17)	(5.17)	(4.60)	(4.60)	(4.79)	(4.68)
GF × NAAQS		−3.18***	−3.18***	−1.55**	−2.79***	−1.32**	−2.75***
		(−5.70)	(−5.70)	(−3.26)	(−5.68)	(−2.79)	(−4.79)
MMBTU		−0.18	−0.18	−0.14	−0.06	−0.44***	−0.06
		(−1.09)	(−1.09)	(−0.82)	(−0.36)	(−5.66)	(−0.35)
GF × MMBTU		−0.98***	−0.98***	−1.00***	−0.95***	−0.85***	−0.94***
		(−5.89)	(−5.89)	(−5.92)	(−5.62)	(−10.08)	(−5.21)
Year FE	X	X	X	X	X	X	X
State FE	X	X	X	X	X	X	X
Utility FE	X	X	X	X	X	X	
Market Controls							
Sulfur Controls				X	X	X	X
Observations	10,227	10,227	10,227	9,706	10,227	16,181	10,049
R^2	0.419	0.431	0.431	0.438	0.440	0.407	0.442