Technology Lock-In and Costs of Delayed Climate Policy

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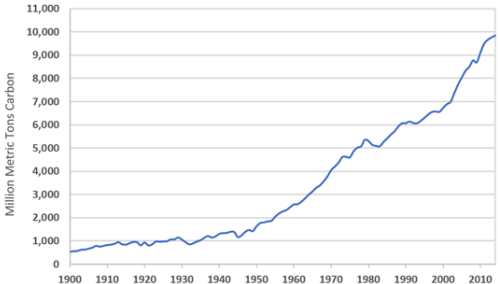
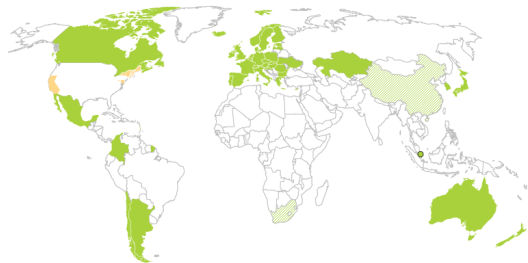
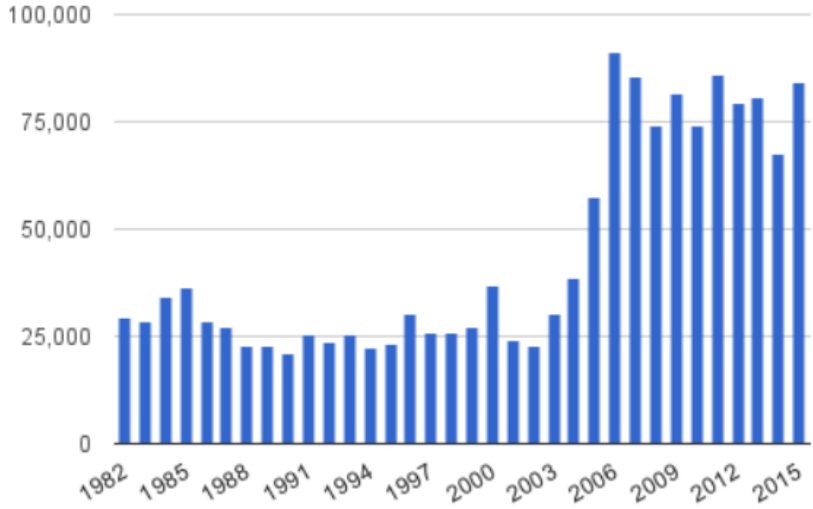
Motivation





Global trend in carbon emissions (EIA); Map of countries pricing carbon (NYT)

Motivation



New coal power capacity added wordwide (MW) (Global Coal Plant Tracker)

Overview

- Research question:
  - Does the lack of carbon pricing today mitigate the effectiveness of future carbon pricing?
- Approach:
  - IV: Quantify importance of initial energy prices for current energy intensity ("lock-in")
  - Production function estimation: Assess contributions of initial tech vs. capital adjustment costs

Results Preview

- Empirical evidence of lock-in in U.S. manufacturing:
  - Initial electricity prices matter
  - Elasticity wrt initial prices 25% of elasticity wrt current prices
  - Initial coal and oil prices still influential today
  - Limited heterogeneous effects by plant age
- Mechanisms:
  - Persistent differences in input productivities are important
  - Contribution of capital adjustment costs is comparatively small

Literature and Contributions

- Path dependence in transitions to clean energy
  (Acemoglu, Aghion, Burzysten, Hemous 2012; Acemoglu, Aghion, Barrage, Hemous 2019; Fried 2018; Meng 2021; Linn 2008)
  - This paper: first estimate of importance of entry-year energy prices for energy intensity in subsequent years, duration of and mechanisms for their importance
- Industrial environmental regulation
  (Fowlie, Holland, Mansur 2011; Ryan 2012; Greenstone, List, Syverson 2012; Shapiro and Walker 2018)
  - This paper: generalizable explanation for why dynamic responses arise
- Climate-economy integrated assessment models
  (Nordhaus and Boyer 2000)
  - This paper: new microfoundation for rate of decarbonization

Outline

1. Setting
2. Conceptual Framework
3. Data
4. Econometric Model
5. Empirical Evidence of Lock-In
6. Discussion and Concluding Remarks

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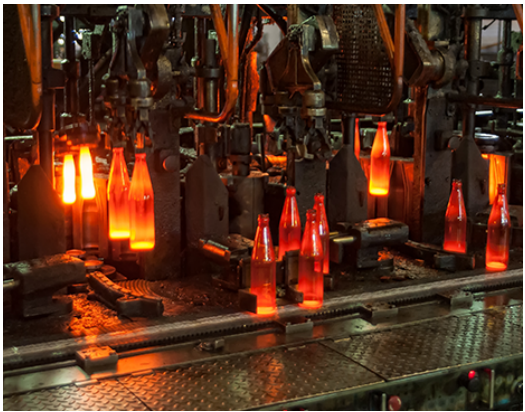
Energy Use in U.S. Manufacturing



- 25% of energy consumed
- 25% of GHG emissions
- Mostly purchased electricity
- Accounts for almost all of the predicted increase in U.S. energy use in the next decade

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Overview

Three margins of adjustment

- Incumbent plants observe capital stocks, productivities, and prices
  - Decide whether to exit
  - If not, choose flexible inputs (labor, energy) and capital investment subject to fixed and convex adjustment costs
- Potential entrants observe productivity draws and prices
  - Decide whether to enter
  - If so, choose labor, energy, and capital fully flexibly
- Illustrate using simple, two-period model
  - Paper has dynamic multi-period model under alternative expectations of energy prices

Lock-In Mechanism 1

Selection Effect on Entrants' Productivity

- Production function:

$$Y(K, L, E; \beta) = \alpha \left(K^{\rho} + L^{\rho} + (\beta E)^{\rho}\right)^{\frac{\nu}{\rho}}$$

- Potential entrant i draws productivities α_i and β_i and solves:

$$\max_{K,L,E} \pi(K, L, E; \alpha_i, \beta_i) = pY(K, L, E; \alpha_i, \beta_i) - rK - wL - p_e E$$

- Enter if profits exceed fixed costs of entry

- Entrant's problem yields a cutoff rule: enter if

$$\beta_i \geq \beta^{entry}(p_E)$$

Lock-In Mechanism 2

Capital Adjustment Costs

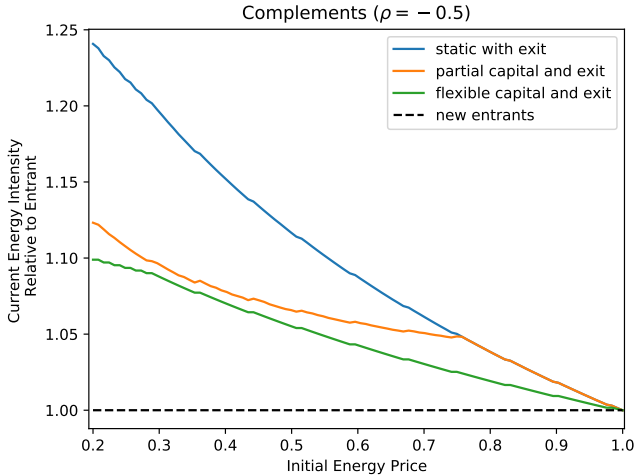
- Plants observe prices and current capital K and choose their capital in the next period, K', to solve

$$\max_{K'} \begin{cases} \pi^*(K'; p'_E, \alpha_i, \beta_i) - \gamma_0 - r(K' - K) - \gamma_1(K' - K)^2 & \text{if } K' \neq K \\ \pi^*(K; p'_E, \alpha_i, \beta_i) & \text{otherwise} \end{cases}$$

- γ_0 and γ_1 are fixed and convex adjustment costs

Lock-in Mechanisms

Simulation Results



▸ Unanticipated Prices ▸ Perfect Foresight

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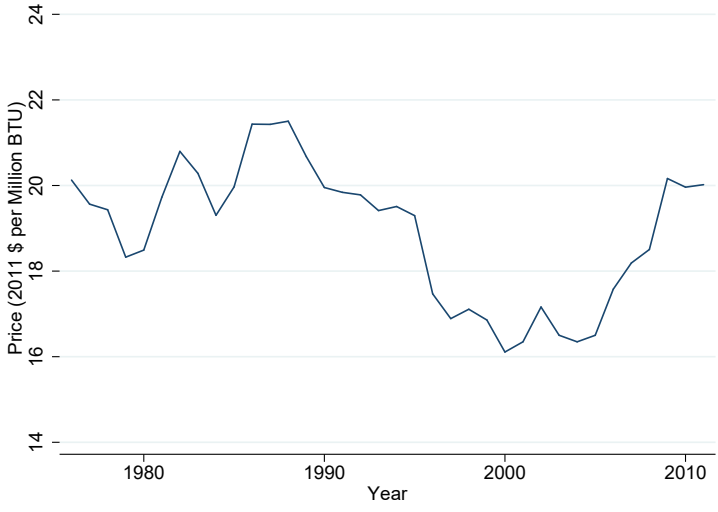
Data

- Manufacturing inputs, outputs, entry/exit dates
  - restricted-access U.S. Census microdata, 1976-2011
  - Annual Survey of Manufacturing, Census of Manufacturing, Manufacturing Energy Consumption Survey, Longitudinal Business Database
  - universe of U.S. manufacturing plants opening after 1975
  - measure electricity prices, energy intensity
- State fuel prices and shares
  - Energy Information Administration (EIA) State Energy Data System
- Electricity prices
  - EIA, OpenEI Databases

▸ Sample Restrictions ▸ Summary Statistics

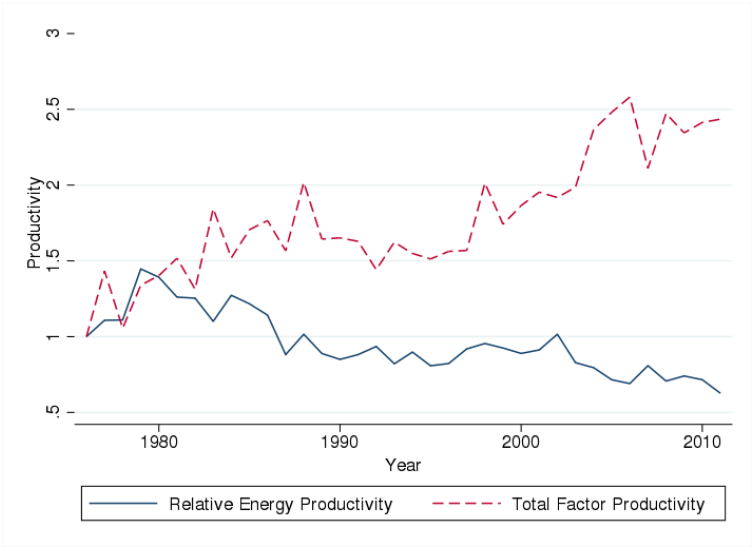
Electricity Price Trends



Fuel Price Trends Fuel Share Trends

Energy Intensity Trends

Productivity Trends



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IV Analysis

- How do initial (log) electricity prices affect current (log) energy intensity and productivity, conditional on current electricity prices?

$$y_{i,t} = \beta_0 p_{j,s,t_0} + \beta_1 p_{i,t} + \tau_{j,t,t_0} + \gamma_{s,j} + \epsilon_{i,t}$$

- $y_{i,t} \in \{\frac{E}{R_{i,t}}, \omega^E_{i,t}\}$
- plant i, industry j, state s, current year t, entry year t_0
- cluster by state

Instruments

- Bartik-style interaction of state electricity generation shares and current national fuel prices (Ganapati, Shapiro, and Walker 2020)

$$Z_{s,f,t} = [\rho_{-s,f,t} \times \sigma_{s,f,1976}]$$

- $\rho_{-s,t,f}$: mean of other states' log fuel price in year t
- $\sigma_{s,f,1976}$: share of fuel f in electricity generation in state s in 1976
- for each fuel $f \in \{\text{coal, natural gas, oil}\}$
- for current and initial prices

▸ Fuel Price Trends ▸ Fuel Generation Shares ▸ Fuel Generation Shares Change ▸ Correlation with State Characteristics

Estimating Relative Productivities

- Estimate:

$$Y_{jt} = \exp(\omega_{jt}^H)\left(\beta_K K_{jt}^{\frac{\sigma-1}{\sigma}} + L_{jt}^{\frac{\sigma-1}{\sigma}} + (\exp(\omega_{jt}^E)E_{jt})^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\nu\sigma}{\sigma-1}} \times \exp(\epsilon_{jt})$$

- $\omega_{j,t}^E$: Estimating equations use logs of ratio of labor and energy FOCs:

$$l_{jt} - e_{jt} = -\sigma(w_{jt} - p_{jt}^E) + (1-\sigma)\omega_{jt}^E$$

- $\omega_{j,t}^H$: Given ω_{jt}^E, recover TFP ω_{jt}^H from energy FOC
- GMM estimation using AR(1) evolution of productivity shocks

▸ Estimation Details ▸ Parameter Estimates

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Effects of Weighted Fuel Prices on Electricity Prices

First Stage

	$\log(Initial\_Electricity\_Price_{it_0})$	$\log(Current\_Electricity\_Price_{it})$
	(1)	(2)
$Coal\_Share_{s,1976} \times Current\_Coal\_Price_{-s,t}$	0.013	0.065*
	(0.009)	(0.035)
$Natural\_Gas\_Share_{s,1976} \times Current\_Natural\_Gas\_Price_{-s,t}$	-0.006*	0.058***
	(0.003)	(0.012)
$Petroleum\_Share_{s,1976} \times Current\_Petroleum\_Price_{-s,t}$	0.003	0.012
	(0.003)	(0.010)
$Coal\_Share_{s,1976} \times Initial\_Coal\_Price_{-s,t_0}$	0.220***	0.055**
	(0.049)	(0.023)
$Natural\_Gas\_Share_{s,1976} \times Initial\_Natural\_Gas\_Price_{-s,t_0}$	0.056***	0.011*
	(0.012)	(0.006)
$Petroleum\_Share_{s,1976} \times Initial\_Petroleum\_Price_{-s,t_0}$	0.036***	0.019***
	(0.012)	(0.005)
Industry × Year × Entry Year Fixed Effects	Yes	Yes
Industry × State Fixed Effects	Yes	Yes
N	1294000	1294000

Effects of Weighted Fuel Prices on Energy Intensity

Reduced Form

	$\log(Electricity\_Intensity_{i,t})$	$\log(Electricity\_Intensity_{i,t})$	$\log(CO_2\_Intensity_{i,t})$	$\log(BTU\_Intensity_{i,t})$
		Electricity-Intensive Industries		
	(1)	(2)	(3)	(4)
$Coal\_Share_{s,1976} \times Current\_Coal\_Price_{-s,t}$	0.043	0.055	-0.019	0.073*
	(0.031)	(0.036)	(0.041)	(0.039)
$Natural\_Gas\_Share_{s,1976} \times Current\_Natural\_Gas\_Price_{-s,t}$	-0.053***	-0.052***	-0.053***	-0.056***
	(0.011)	(0.012)	(0.011)	(0.012)
$Petroleum\_Share_{s,1976} \times Current\_Petroleum\_Price_{-s,t}$	-0.000	-0.004	0.001	0.001
	(0.009)	(0.009)	(0.010)	(0.010)
$Coal\_Share_{s,1976} \times Initial\_Coal\_Price_{-s,t_0}$	-0.121***	-0.123***	-0.163***	-0.129***
	(0.028)	(0.031)	(0.029)	(0.029)
$Natural\_Gas\_Share_{s,1976} \times Initial\_Natural\_Gas\_Price_{-s,t_0}$	-0.003	-0.013	0.001	0.002
	(0.009)	(0.012)	(0.008)	(0.008)
$Petroleum\_Share_{s,1976} \times Initial\_Petroleum\_Price_{-s,t_0}$	-0.028***	-0.031***	-0.028***	-0.024***
	(0.005)	(0.006)	(0.005)	(0.005)
Industry × Year × Entry Year Fixed Effects	Yes	Yes	Yes	Yes
Industry × State Fixed Effects	Yes	Yes	Yes	Yes
N	1294000	955000	1294000	1294000

▸ Fuel Share Trends

Effects of Initial and Current Electricity Prices on Energy Intensity

OLS & IV

	$\log(Electricity\_Intensity_{i,t})$	$\log(Electricity\_Intensity_{i,t})$	$\log(CO_2\_Intensity_{i,t})$	$\log(BTU\_Intensity_{i,t})$
		Electricity-Intensive Industries		
	(1)	(2)	(3)	(4)
Panel A: OLS				
$\log(Current\_Electricity\_Price_{it})$	-0.851***	-0.831***	-0.824***	-0.807***
	(0.012)	(0.011)	(0.010)	(0.009)
$\log(Initial\_Electricity\_Price_{it_0})$	-0.040***	-0.037***	-0.028***	-0.026**
	(0.009)	(0.010)	(0.010)	(0.010)
Panel B: IV				
$\log(Current\_Electricity\_Price_{it})$	-0.764***	-0.734***	-0.829***	-0.761***
	(0.090)	(0.104)	(0.072)	(0.087)
$\log(Initial\_Electricity\_Price_{it_0})$	-0.165***	-0.232***	-0.289***	-0.144**
	(0.051)	(0.059)	(0.079)	(0.059)
K-P F stat	12.1	11.9	12.1	12.1
Industry × Year × Entry Year FE	Yes	Yes	Yes	Yes
Industry × State FE	Yes	Yes	Yes	Yes
N	1294000	955000	1294000	1294000

▸ Robustness ▸ Other Outcomes

Heterogeneous Effects of Initial Electricity Prices on Energy Intensity

IV

	$\log(Electricity\_Intensity_{i,t})$	$\log(Electricity\_Intensity_{i,t})$ Electricity-Intensive Industries	$\log(CO_2\_Intensity_{i,t})$	$\log(BTU\_Intensity_{i,t})$
	(1)	(2)	(3)	(4)
$\log(Current\_Electricity\_Price_{it})$	-0.871***	-0.856***	-1.136***	-0.903***
	(0.061)	(0.070)	(0.097)	(0.069)
$\log(Initial\_Electricity\_Price_{it_0})$	-0.134**	-0.186***	-0.140**	-0.076
	(0.052)	(0.062)	(0.061)	(0.054)
$\log(Initial\_Electricity\_Price_{it_0}) \times Age_{it}$	0.006**	0.006	0.006	0.004
	(0.003)	(0.004)	(0.004)	(0.004)
K-P F stat	13.3	14.2	13.3	13.3
Industry $\times$ Year $\times$ Entry Year FE	Yes	Yes	Yes	Yes
Industry $\times$ State FE	Yes	Yes	Yes	Yes
N	1294000	955000	1294000	1294000

Effects of Weighted Fuel Prices on Productivity

Reduced Form

	$\log(Energy\_Productivity_{i,t})$	$\log(Energy\_Productivity_{i,t})$ Electricity-Intensive Industries	$\log(TFP_{i,t})$	$\log(TFP_{i,t})$ Electricity-Intensive Industries
	(1)	(2)	(3)	(4)
$Coal\_Share_{s,1976} \times Current\_Coal\_Price_{-s,t}$	-0.088*	-0.082	-0.035**	-0.034*
	(0.048)	(0.051)	(0.017)	(0.018)
$Natural\_Gas\_Share_{s,1976} \times Current\_Natural\_Gas\_Price_{-s,t}$	0.037***	0.046***	0.012***	0.005
	(0.013)	(0.012)	(0.004)	(0.004)
$Petroleum\_Share_{s,1976} \times Current\_Petroleum\_Price_{-s,t}$	0.008	0.013	-0.010***	-0.009***
	(0.013)	(0.012)	(0.002)	(0.003)
$Coal\_Share_{s,1976} \times Initial\_Coal\_Price_{-s,t_0}$	0.178***	0.171***	0.037*	0.041*
	(0.041)	(0.044)	(0.022)	(0.025)
$Natural\_Gas\_Share_{s,1976} \times Initial\_Natural\_Gas\_Price_{-s,t_0}$	-0.018	-0.011	0.006*	0.011***
	(0.017)	(0.017)	(0.004)	(0.004)
$Petroleum\_Share_{s,1976} \times Initial\_Petroleum\_Price_{-s,t_0}$	0.035***	0.035***	-0.005	-0.002
	(0.008)	(0.011)	(0.005)	(0.006)
N	1294000	955000	1294000	955000
Industry × Year × Entry Year Fixed Effects	Yes	Yes	Yes	Yes
Industry × State Fixed Effects	Yes	Yes	Yes	Yes

Effects of Initial and Current Electricity Prices on Productivity

OLS & IV

	$\log(Energy\_Productivity_{i,t})$	$\log(Energy\_Productivity_{i,t})$ Electricity-Intensive Industries	$\log(TFP_{i,t})$	$\log(TFP_{i,t})$ Electricity-Intensive Industries
	(1)	(2)	(3)	(4)
Panel A: OLS				
$\log(Current\_Electricity\_Price_{i,t})$	0.881***	0.860***	0.060***	0.060***
	(0.023)	(0.020)	(0.007)	(0.009)
$\log(Initial\_Electricity\_Price_{i,t_0})$	0.080***	0.093***	-0.037***	-0.047***
	(0.019)	(0.023)	(0.008)	(0.012)
Panel B: IV				
$\log(Current\_Electricity\_Price_{i,t})$	0.525***	0.673***	0.088	-0.017
	(0.138)	(0.139)	(0.127)	(0.119)
$\log(Initial\_Electricity\_Price_{i,t_0})$	0.349***	0.319***	0.049	0.124
	(0.122)	(0.126)	(0.077)	(0.083)
K-P F stat	12.1	11.9	12.1	11.9
N	1294000	955000	1294000	955000
Industry × Year × Entry Year FE	Yes	Yes	Yes	Yes
Industry × State FE	Yes	Yes	Yes	Yes

▸ Robustness ▸ Heterogeneity

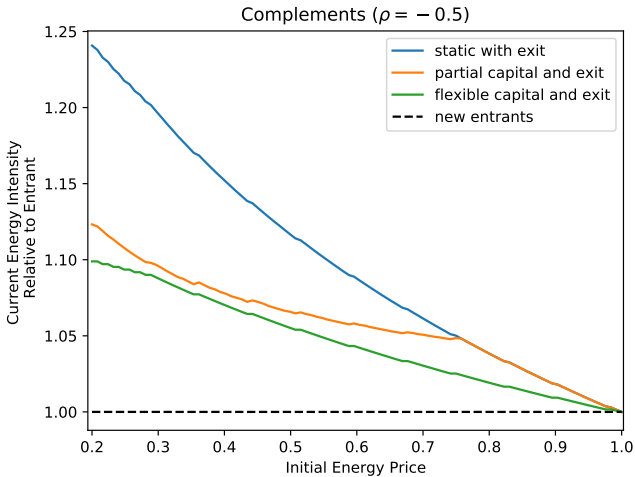
Heterogeneous Effects of Initial Energy Prices on Energy Intensity

IV

	$\log(Electricity\_Intensity_{i,t})$	$\log(CO_2\_Intensity_{i,t})$	$\log(BTU\_Intensity_{i,t})$	$\log(Energy\_Productivity_{i,t})$	$\log(TFP_{i,t})$
	(1)	(2)	(3)	(4)	(5)
$\log(Current\_Electricity\_Price_{i,t})$	-0.871***	-1.136***	-0.903***	0.739***	0.109
	(0.061)	(0.097)	(0.069)	(0.131)	(0.096)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.134**	-0.140**	-0.076	0.250*	0.097
	(0.052)	(0.061)	(0.054)	(0.130)	(0.095)
$\log(Initial\_Electricity\_Price_{i,t_0}) \times Age_{i,t}$	0.006**	0.006	0.004	-0.006	-0.010***
	(0.003)	(0.004)	(0.004)	(0.007)	(0.003)
K-P F stat	13.3	13.3	13.3	13.3	13.3
N	1294000	1294000	1294000	1294000	1294000
Industry × Year × Entry Year FE	Yes	Yes	Yes	Yes	Yes
Industry × State FE	Yes	Yes	Yes	Yes	Yes

Lock-in Mechanisms

Simulation Results



Policy Implications

- Timely implementation of carbon pricing
  - "Hysteresis" means that temporary carbon pricing will have an effect
- Vintage regulations
  - Target policy to plants that entered during low energy price regimes
- Directed technological change
  - Subsidies for creating efficient technologies that can be adopted initially

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Concluding Remarks

- Technology lock-in is important
  - Entry-year electricity prices have persistent effects on energy use
  - Initial raw fuels prices matter even after use of these fuels declines
  - Effect persists throughout a plant's lifetime
- Lock-in can be explained by persistent differences in inputs' productivity
- Estimates are plausible lower bounds on importance of entry-year prices

Sample Restrictions

- Exclude entry pre-1976
- Exclude imputed administrative records
- Exclude observations with missing, negative, or zero revenue, inputs, prices
- Exclude outliers with inputs $> 100\times$ 99^{th} percentile of distribution
- Exclude outliers with electricity prices $> 10\times$ or $< 1/10$ annual median price
- Linearly interpolate raw fuels inputs based on MECS + raw fuels expenditures
- Recursively calculate capital stocks for missing years using calibrated depreciation

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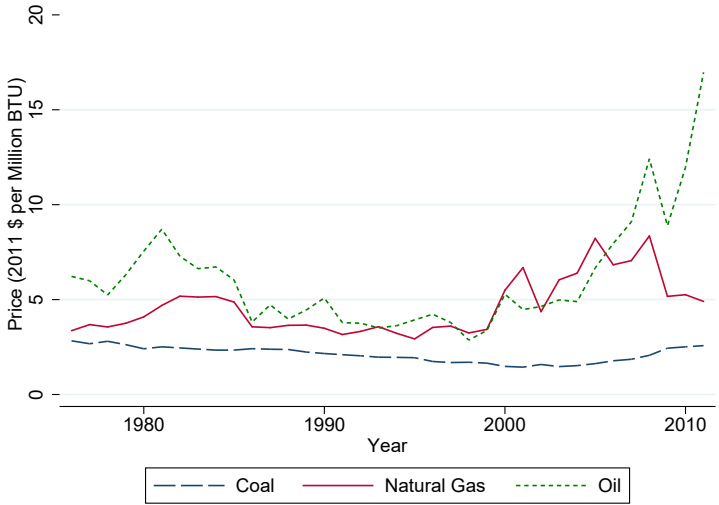
Fuel Price Trends



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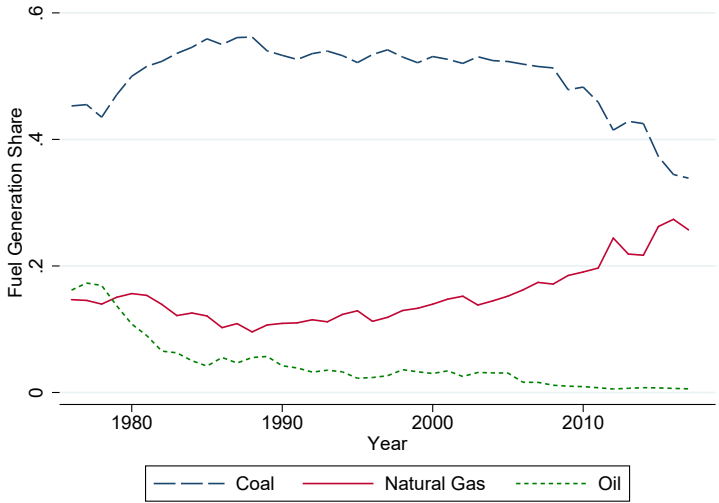
Fuel Share Trends



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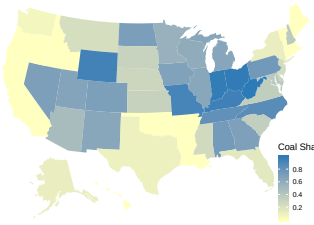
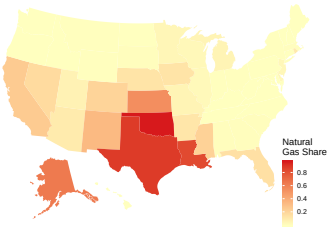
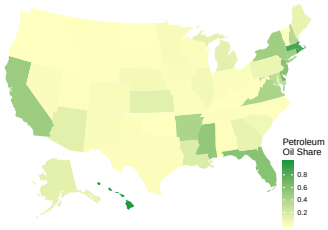
Fuel Electricity Generation Shares in 1976



(a) Coal Share



(b) Natural Gas Share



(c) Petroleum Oil Share

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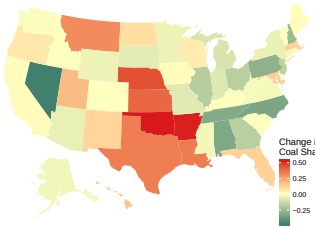
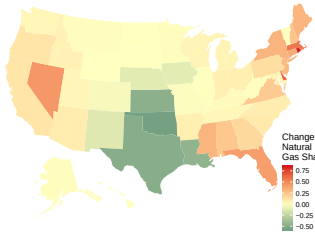
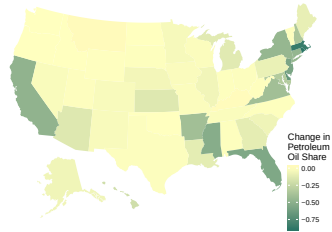
Change in Fuel Electricity Generation Shares, 1976-2011



(a) Change in Coal Share



(b) Change in Natural Gas Share



(c) Change in Petroleum Oil Share

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Correlation of State Characteristics with Fuel Shares

	Coal Share (1)	Natural Gas Share (2)	Petroleum Share (3)
Unemployment Rate	-0.022	-0.039*	-0.001
	(0.033)	(0.022)	(0.023)
State Per Capita Income (1000s)	0.005	0.048	0.034
	(0.043)	(0.029)	(0.029)
Mean Household Income (1000s)	-0.001	-0.000	0.001
	(0.001)	(0.001)	(0.001)
Share Any College Education	-0.030*	-0.015	0.007
	(0.016)	(0.011)	(0.011)
Share White	0.008	0.001	-0.009*
	(0.007)	(0.005)	(0.005)
Share Black	0.004	0.003	-0.003
	(0.007)	(0.005)	(0.005)
Population (1000s)	-0.004	0.005	0.001
	(0.010)	(0.007)	(0.007)
Household Size	0.506	0.517	-0.215
	(0.673)	(0.454)	(0.458)
R-squared	0.266	0.154	0.443
N	51	51	51

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Robustness 1/2

IV

	$\log(Electricity\_Intensity_{i,t})$	$\log(Electricity\_Intensity_{i,t})$ Electricity-Intensive Industries	$\log(CO_2\_Intensity_{i,t})$	$\log(BTU\_Intensity_{i,t})$
	(1)	(2)	(3)	(4)
Panel A: Main Results				
$\log(Current\_Electricity\_Price_{it})$	-0.764***	-0.734***	-0.829***	-0.761***
	(0.090)	(0.104)	(0.072)	(0.087)
$\log(Initial\_Electricity\_Price_{it_0})$	-0.165***	-0.232***	-0.289***	-0.144**
	(0.051)	(0.059)	(0.079)	(0.059)
K-P F stat	12.1	11.9	12.1	12.1
N	1294000	955000	1294000	1294000
Panel B: Year × Industry, First Year × Industry, State × Industry FE				
$\log(Current\_Electricity\_Price_{it})$	-0.770***	-0.726***	-0.831***	-0.763***
	(0.097)	(0.106)	(0.080)	(0.095)
$\log(Initial\_Electricity\_Price_{it_0})$	-0.178***	-0.226***	-0.319***	-0.186***
	(0.051)	(0.070)	(0.074)	(0.057)
K-P F stat	9.7	10.2	9.7	9.7
N	1294000	955000	1294000	1294000
Panel C: Unweighted				
$\log(Current\_Electricity\_Price_{it})$	-0.821***	-0.809***	-0.883***	-0.827***
	(0.044)	(0.044)	(0.045)	(0.041)
$\log(Initial\_Electricity\_Price_{it_0})$	-0.109**	-0.153**	-0.172***	-0.074
	(0.052)	(0.067)	(0.059)	(0.045)
K-P F stat	11.6	10.8	11.6	11.6
N	1294000	955000	1294000	1294000

Robustness 2/2

IV

	$\log(Electricity\_Intensity_{i,t})$	$\log(Electricity\_Intensity_{i,t})$ Electricity-Intensive Industries	$\log(CO_2\_Intensity_{i,t})$	$\log(BTU\_Intensity_{i,t})$
	(1)	(2)	(3)	(4)
Panel D: State × Year Trends				
$\log(Current\_Electricity\_Price_{it})$	-0.958***	-1.033***	-1.003***	-1.053***
	(0.127)	(0.144)	(0.081)	(0.129)
$\log(Initial\_Electricity\_Price_{i_0})$	-0.219***	-0.311***	-0.218***	-0.206***
	(0.062)	(0.075)	(0.062)	(0.059)
K-P F stat	11.9	11.3	11.9	11.9
N	1294000	955000	1294000	1294000
Panel E: Impute CO2, BTU from MECS only				
$\log(Current\_Electricity\_Price_{it})$	-0.764***	-0.734***	-0.811***	-0.786***
	(0.090)	(0.104)	(0.085)	(0.085)
$\log(Initial\_Electricity\_Price_{i_0})$	-0.165***	-0.232***	-0.193***	-0.152**
	(0.051)	(0.059)	(0.068)	(0.063)
K-P F stat	12.1	11.9	12.1	12.1
N	1294000	955000	1294000	1294000
Panel F: Exclude Years with Imputed CO2 and BTU Values				
$\log(Current\_Electricity\_Price_{it})$	-0.625***	-0.585***	-0.800***	-0.564***
	(0.137)	(0.161)	(0.098)	(0.128)
$\log(Initial\_Electricity\_Price_{i_0})$	-0.368***	-0.451***	-0.715***	-0.256**
	(0.091)	(0.099)	(0.134)	(0.106)
K-P F stat	11.1	11.9	11.1	11.1
N	312000	225000	312000	312000
Panel G: MECS Years Only				
$\log(Current\_Electricity\_Price_{it})$	-0.685***	-0.696***	-0.722***	-0.725***
	(0.116)	(0.138)	(0.107)	(0.104)
$\log(Initial\_Electricity\_Price_{i_0})$	-0.343***	-0.424***	-0.370***	-0.367***
	(0.089)	(0.125)	(0.085)	(0.086)
K-P F stat	9.4	10.0	9.4	9.4 [1em] N
266000	192000	266000	266000	

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Robustness 1/2

IV

	$\log(Energy\_Productivity_{i,t})$	$\log(Energy\_Productivity_{i,t})$ Electricity-Intensive Industries	$\log(TFP_{i,t})$	$\log(TFP_{i,t})$ Electricity-Intensive Industries
	(1)	(2)	(3)	(4)
Panel A: Main Results				
$\log(Current\_Electricity\_Price_{i,t})$	0.525***	0.673***	0.088	-0.017
	(0.138)	(0.139)	(0.127)	(0.119)
$\log(Initial\_Electricity\_Price_{i,t_0})$	0.349***	0.319***	0.049	0.124
	(0.122)	(0.126)	(0.077)	(0.083)
K-P F stat	12.1	11.9	12.1	11.9
N	1294000	955000	1294000	955000
Panel B: Year × Industry, First Year × Industry, State × Industry FE				
$\log(Current\_Electricity\_Price_{i,t})$	0.512***	0.671***	0.136	0.047
	(0.169)	(0.150)	(0.118)	(0.113)
$\log(Initial\_Electricity\_Price_{i,t_0})$	0.330***	0.270***	0.021	0.087
	(0.100)	(0.115)	(0.074)	(0.098)
K-P F stat	9.7	10.2	9.7	10.2
N	1294000	955000	1294000	955000
Panel C: State × Year Trends				
$\log(Current\_Electricity\_Price_{i,t})$	0.928***	1.109***	0.040	-0.049
	(0.295)	(0.289)	(0.146)	(0.126)
$\log(Initial\_Electricity\_Price_{i,t_0})$	0.322***	0.352***	0.089	0.141
	(0.140)	(0.156)	(0.082)	(0.093)
K-P F stat	11.9	11.3	11.9	11.3
N	1294000	955000	1294000	955000

Robustness 2/2

IV

	$\log(Energy\_Productivity_{i,t})$ (1)	$\log(Energy\_Productivity_{i,t})$ Electricity-Intensive Industries (2)	$\log(TFP_{i,t})$ (3)	$\log(TFP_{i,t})$ Electricity-Intensive Industries (4)
Panel D: Unweighted				
$\log(Current\_Electricity\_Price_{i,t})$	0.465***	0.589***	0.174	0.059
	(0.124)	(0.123)	(0.105)	(0.078)
$\log(Initial\_Electricity\_Price_{i,t_0})$	0.425***	0.412***	-0.078	0.017
	(0.087)	(0.092)	(0.049)	(0.055)
K-P F stat	11.6	10.8	11.6	10.8
N	1294000	955000	1294000	955000
Panel E: Impute CO2, BTU from MECS only				
$\log(Current\_Electricity\_Price_{i,t})$	0.525***	0.673***	0.088	-0.017
	(0.138)	(0.139)	(0.127)	(0.119)
$\log(Initial\_Electricity\_Price_{i,t_0})$	0.349***	0.319***	0.049	0.124
	(0.122)	(0.126)	(0.077)	(0.083)
K-P F stat	12.1	11.9	12.1	11.9
N	1294000	955000	1294000	955000
Panel F: Exclude Years with Imputed CO2 and BTU Values				
$\log(Current\_Electricity\_Price_{i,t})$	0.413***	0.421***	0.103	0.049
	(0.150)	(0.188)	(0.099)	(0.095)
$\log(Initial\_Electricity\_Price_{i,t_0})$	0.376***	0.557***	0.091	0.132
	(0.193)	(0.186)	(0.102)	(0.105)
K-P F stat	11.1	11.9	11.1	11.9
N	312000	225000	312000	225000
Panel G: MECS Years Only				
$\log(Current\_Electricity\_Price_{i,t})$	0.411***	0.415***	0.126	0.122
	(0.144)	(0.162)	(0.090)	(0.092)
$\log(Initial\_Electricity\_Price_{i,t_0})$	0.503***	0.573***	0.047	0.097
	(0.177)	(0.193)	(0.101)	(0.111)
K-P F stat	9.4	10.0	9.4	10.0
N	266000	192000	266000	192000

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Other Outcomes

IV

	(1)	(2)	(3)
Panel A: Energy Inputs (Levels)			
	$\log(Quantity\_Electricity_{i,t})$	$\log(Total\_CO2_{i,t})$	$\log(Total\_BTU_{i,t})$
$\log(Current\_Electricity\_Price_{i,t})$	-0.308*	-0.373**	-0.305*
	(0.170)	(0.183)	(0.178)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.240*	-0.364***	-0.218*
	(0.133)	(0.112)	(0.124)
Panel B: Other Manufacturing Inputs			
	$\log(Labor\_Hours_{i,t})$	$\log(Materials\_Costs_{i,t})$	$\log(Capital\_Investment_{i,t})$
$\log(Current\_Electricity\_Price_{i,t})$	0.470***	0.421*	0.391
	(0.153)	(0.239)	(0.287)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.109	-0.136	0.434*
	(0.124)	(0.146)	(0.247)
K-P F stat	12.1	12.1	12.1
N	1294000	1294000	1294000
Industry × Year × Entry Year FE	Yes	Yes	Yes
Industry × State FE	Yes	Yes	Yes

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Summary Statistics

	All Industries	Electricity-Intensive Industries
	(1)	(2)
Year	1997	1997
	(8.595)	(8.540)
Entry Year	1988	1988
	(8.894)	(8.760)
Plant Age (years)	9.243	9.297
	(8.000)	(7.997)
Current Electricity Price ($ per kWh)	0.087	0.085
	(0.036)	(0.034)
Initial Electricity Price ($ per kWh)	0.088	0.088
	(0.032)	(0.030)
Cost of Purchased Electricity (1000$)	275.4	203.4
	(2065)	(958)
Quantity of Purchased Electricity (1000 kWh)	4411	3175
	(51160)	(22430)
Electricity Intensity (kWh per $ revenue)	0.196	0.208
	(0.500)	(0.500)
CO2 Intensity (kg per $ revenue)	0.122	0.132
	(0.469)	(0.519)
BTU Intensity (million BTU per $ revenue)	0.001	0.002
	(0.006)	(0.007)
N	1294000	955000

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Estimating Relative Productivities

1. Guess production technology parameters $\tilde{\theta} = (\sigma, \nu, \beta_K)$ to recover productivities
2. Estimate AR(1) processes for productivities using OLS to obtain productivity shocks
3. Form moments using these innovations and instruments (lagged (log) inputs and lagged wages and energy prices)
   - Identifying assumption: past inputs and prices are uncorrelated with current shocks to productivity
4. Find $\tilde{\theta}$ that minimizes two-step GMM estimator
5. Estimate at 4-digit NAICS industry level

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Production Function Parameters

	All Industries (1)	Elec. Intensive Industries (2)
Returns to scale ν	0.620	0.679
	(0.292)	(0.256)
Elasticity of substitution σ	0.260	0.237
	(0.195)	(0.186)
Capital productivity β_K	3.411	3.498
	(2.200)	(2.220)
N	1294000	955000

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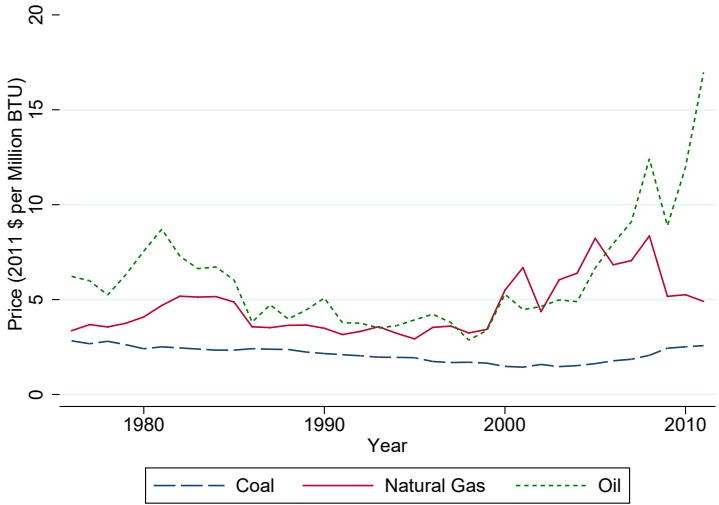
Fuel Price Trends



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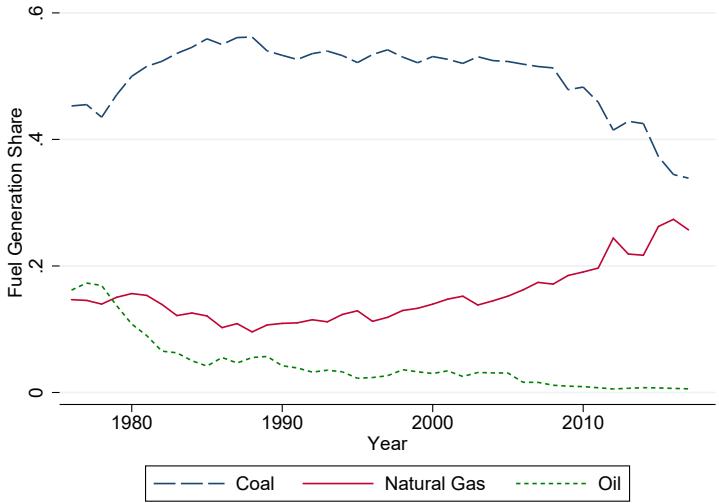
Fuel Share Trends



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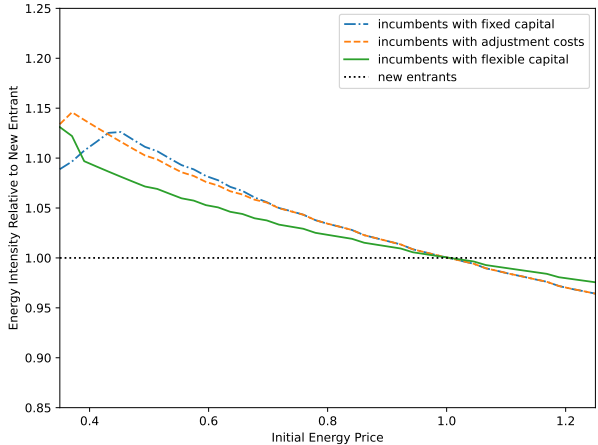
Perfect Foresight Price Change Simulation



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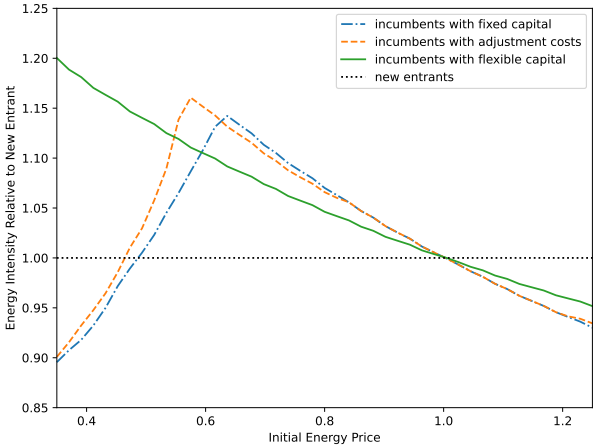
Unanticipated Price Change Simulation



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Heterogeneity 1/2

IV

	$\log(Electricity\_Intensity_{i,t})$	$\log(CO_2\_Intensity_{i,t})$	$\log(BTU\_Intensity_{i,t})$	$\log(Energy\_Productivity_{i,t})$	$\log(TFP_{i,t})$
	(1)	(2)	(3)	(4)	(5)
Panel A: Metals and Metal Products					
$\log(Current\_Electricity\_Price_{i,t})$	-0.770***	-0.838***	-0.768***	0.543***	0.091
	(0.092)	(0.075)	(0.090)	(0.137)	(0.125)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.140*	-0.286**	-0.114	0.313*	0.072
	(0.071)	(0.111)	(0.084)	(0.159)	(0.078)
$\log(Initial\_Electricity\_Price_{i,t_0})\times 1[Industry_2]$	-0.024	0.090	-0.049	-0.029	-0.123
	(0.203)	(0.233)	(0.224)	(0.309)	(0.093)
K-P F stat	8.1	8.1	8.1	8.1	8.1
Panel B: Non-Metallic Minerals					
$\log(Current\_Electricity\_Price_{i,t})$	-0.766***	-0.826***	-0.760***	0.528***	0.086
	(0.091)	(0.073)	(0.088)	(0.136)	(0.127)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.210***	-0.299***	-0.173**	0.393***	0.040
	(0.053)	(0.084)	(0.072)	(0.117)	(0.073)
$\log(Initial\_Electricity\_Price_{i,t_0})\times 1[Industry_2]$	0.496**	0.091	0.300	-0.529	0.106
	(0.239)	(0.309)	(0.323)	(0.517)	(0.258)
K-P F stat	10.7	10.7	10.7	10.7	10.7
Panel C: Chemical Products					
$\log(Current\_Electricity\_Price_{i,t})$	-0.759***	-0.825***	-0.756***	0.517***	0.089
	(0.088)	(0.072)	(0.086)	(0.143)	(0.127)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.138**	-0.260***	-0.112*	0.344***	0.053
	(0.060)	(0.082)	(0.064)	(0.116)	(0.078)
$\log(Initial\_Electricity\_Price_{i,t_0})\times 1[Industry_2]$	-0.318	-0.323	-0.383	0.026	-0.021
	(0.293)	(0.304)	(0.294)	(0.545)	(0.164)
K-P F stat	11.7	11.7	11.7	11.7	11.7
Panel D: Agricultural Machinery					
$\log(Current\_Electricity\_Price_{i,t})$	-0.764***	-0.834***	-0.765***	0.525***	0.086
	(0.090)	(0.072)	(0.087)	(0.137)	(0.126)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.166***	-0.295***	-0.159**	0.384***	0.043
	(0.054)	(0.078)	(0.060)	(0.130)	(0.079)
$\log(Initial\_Electricity\_Price_{i,t_0})\times 1[Industry_2]$	0.005	0.202	0.345	-0.640	0.156
	(0.206)	(0.226)	(0.215)	(0.420)	(0.257)
K-P F stat	11.3	11.3	11.3	11.3	11.3
Panel E: Electrical Goods					
$\log(Current\_Electricity\_Price_{i,t})$	-0.766***	-0.830***	-0.762***	0.528***	0.086
	(0.090)	(0.072)	(0.087)	(0.138)	(0.127)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.160***	-0.288***	-0.142**	0.335***	0.046
	(0.051)	(0.080)	(0.059)	(0.124)	(0.077)
$\log(Initial\_Electricity\_Price_{i,t_0})\times 1[Industry_2]$	-0.055	0.025	-0.011	0.199	0.136
	(0.178)	(0.173)	(0.174)	(0.256)	(0.209)
K-P F stat	8.7	8.7	8.7	8.7	8.7

Heterogeneity 2/2

IV

	$\log(Electricity\_Intensity_{i,t})$	$\log(CO_2\_Intensity_{i,t})$	$\log(BTU\_Intensity_{i,t})$	$\log(Energy\_Productivity_{i,t})$	$\log(TFP_{i,t})$
	(1)	(2)	(3)	(4)	(5)
Panel F: Transportation Goods					
$\log(Current\_Electricity\_Price_{i,t})$	-0.764***	-0.828***	-0.760***	0.534***	0.084
	(0.090)	(0.073)	(0.088)	(0.137)	(0.127)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.162***	-0.280***	-0.146**	0.338**	0.050
	(0.052)	(0.080)	(0.060)	(0.132)	(0.078)
$\log(Initial\_Electricity\_Price_{i,t_0}) \times 1[Industry_i]$	-0.065	-0.220	0.028	0.153	0.027
	(0.175)	(0.177)	(0.175)	(0.456)	(0.124)
K-P F stat	8.5	8.5	8.5	8.5	8.5
Panel G: Food, Drink, and Tobacco					
$\log(Current\_Electricity\_Price_{i,t})$	-0.770***	-0.837***	-0.767***	0.537***	0.093
	(0.087)	(0.070)	(0.084)	(0.139)	(0.124)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.171***	-0.288***	-0.145**	0.392***	0.020
	(0.056)	(0.079)	(0.061)	(0.125)	(0.081)
$\log(Initial\_Electricity\_Price_{i,t_0}) \times 1[Industry_i]$	0.094	0.030	0.029	-0.682	0.373**
	(0.186)	(0.190)	(0.170)	(0.614)	(0.170)
K-P F stat	12.6	12.6	12.6	12.6	12.6
Panel H: Textile, Leather, and Shoes					
$\log(Current\_Electricity\_Price_{i,t})$	-0.780***	-0.843***	-0.778***	0.525***	0.097
	(0.086)	(0.071)	(0.083)	(0.137)	(0.123)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.168***	-0.296***	-0.149**	0.294**	0.072
	(0.054)	(0.079)	(0.059)	(0.130)	(0.085)
$\log(Initial\_Electricity\_Price_{i,t_0}) \times 1[Industry_i]$	-0.151	-0.180	-0.089	0.896	-0.215
	(0.199)	(0.220)	(0.184)	(0.552)	(0.288)
K-P F stat	8.5	8.5	8.5	8.5	8.5
Panel I: Timber and Furniture					
$\log(Current\_Electricity\_Price_{i,t})$	-0.762***	-0.830***	-0.760***	0.526***	0.087
	(0.089)	(0.071)	(0.088)	(0.138)	(0.126)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.172***	-0.296***	-0.145**	0.388***	0.063
	(0.048)	(0.078)	(0.056)	(0.132)	(0.070)
$\log(Initial\_Electricity\_Price_{i,t_0}) \times 1[Industry_i]$	0.053	0.069	-0.002	-0.377	-0.122
	(0.147)	(0.172)	(0.159)	(0.275)	(0.170)
K-P F stat	8.5	8.5	8.5	8.5	8.5
Panel J: Printing and Paper Products					
$\log(Current\_Electricity\_Price_{i,t})$	-0.778***	-0.840***	-0.773***	0.549***	0.093
	(0.085)	(0.069)	(0.082)	(0.138)	(0.125)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.174**	-0.312***	-0.165**	0.318**	0.033
	(0.068)	(0.080)	(0.064)	(0.139)	(0.078)
$\log(Initial\_Electricity\_Price_{i,t_0}) \times 1[Industry_i]$	0.175	0.262	0.246	0.088	0.096
	(0.232)	(0.242)	(0.233)	(0.457)	(0.165)
K-P F stat	9.2	9.2	9.2	9.2	9.2
Panel K: Miscellaneous Manufacturing					
$\log(Current\_Electricity\_Price_{i,t})$	-0.762***	-0.827***	-0.760***	0.523***	0.086
	(0.090)	(0.072)	(0.087)	(0.139)	(0.128)
$\log(Initial\_Electricity\_Price_{i,t_0})$	-0.133**	-0.263***	-0.113*	0.299**	0.049
	(0.050)	(0.079)	(0.058)	(0.129)	(0.080)
$\log(Initial\_Electricity\_Price_{i,t_0}) \times 1[Industry_i]$	-0.510**	-0.420*	-0.498**	0.817	-0.016
	(0.250)	(0.246)	(0.244)	(0.503)	(0.248)
K-P F stat	12.8	12.8	12.8	12.8	12.8

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