Pollution Abatement Investment under Financial Frictions and Policy Uncertainty

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FRE @ UF

Motivation

- Known: Environmental pollution causes negative externality
  - Damage to health, properties, and natural resources
- Known: Under-investment in pollution abatement
  - 2005 EPA: \$5.9b in capital investment, \$20.7b in operating cost
  - 2005 BEA: \$2,534.7b in physical investment, \$341.9b in R&D investment
- Unknown: Which frictions inhibit firms' pollution abatement investment?
  1. Research Question: the role of financial frictions and policy uncertainty
  2. Economic implications:

     aggregate outcomes and welfare

     design of environmental policies

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Motivating Example

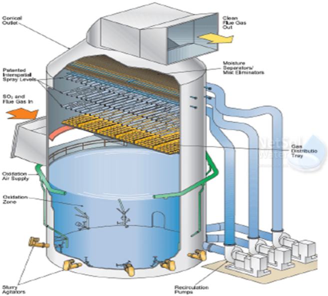

Figure: Pollution Abatement Investment

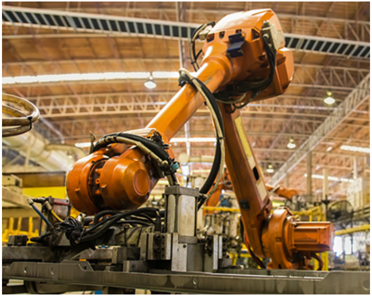

Figure: General Investment

- Key Intertemporal Trade-off: direct and financial cost vs benefit

Motivating Example (Con'd)

Figure: 2030 Net Zero

Figure: Postponed 2050 Net Zero

- An ambiguous policy creates the (environmental) policy uncertainty

Summary of the Paper

Economic mechanism in a simple model:

- An asymmetric trade-off of financial cost and benefit of abatement
- Amplification effect of policy uncertainty on the asymmetric trade-off

Empirical evidence:

- 1: More constrained firms report fewer pollution prevention activities
- 2: Such a relation is more pronounced with high policy uncertainty
- 3: Supplementary results on emission and debt show consistency

Full-blown Quantitative model:

- a GE model with firms, financial constraints, and policy uncertainty
- formalize the intuition for the joint link btw abatement, emission, and debt
- quantitatively account for a set of empirical evidence

Literature Review

1. Policy Implications and Environmental Pollution:
   Acemoglu (2002), Acemoglu, Akcigit, Hanley, and Kerr (2016), Aghion, Dechezlepretre, Hermous, Martin, and van Reenen (2015), Currie, Davis, Greenstone, and Walker (2015), Akey and Appel (2019, 2021), Wang (2022), and among others
   Our paper: Effectiveness depends on financial frictions and policy uncertainty
2. Effects of Policy Uncertainty and General Economic Uncertainty
   Stein and Stone (2013), Baker, Bloom, and Davis (2016), Julio and Yook (2012, 2016), Gulen and Ion (2016), Bhattacharya et al. (2017), Bloom (2009), Bachmann, Moscarini, et al. (2011), Bloom et al (2018), Grigoris and Segal (2023), and among others
   Our paper: Highlight the effect of environmental regulation uncertainty
3. Financial Frictions and Business Cycle
   Kiyotaki and Moore (1997), Gilchrist and Zakrajsek (2012), Jermann and Quadrini (2012), Khan and Thomas (2013), Gilchrist, Sim, and Zakrajsek (2014), Arellano,Bai, and Kehoe (2019), Alfaro, Bloom, and Lin (2018), and among others
   Our paper: A novel trade-off of fin. costs and benefits under env'tl uncertainty
4. Corporate Social Responsibility and Environmental, Social, and Governance
   Hong and Kacperczyk (2009), Kruger (2015), Hong, Li, and Xu (2019), Chen, Kumar, and Zhang (2019), Bansal, Wu, and Yaron (2019), Hsu, Liang, and Matos (2021), Dyck, Lins, Roth, and Wagner (2019), and among others
   Our paper: corporate env'tl decisions under fin. frictions and policy uncertainty

[Mechanism in a Simple Model]

Main intuition in a graphical analysis of marginal cost and benefit

Mechanism: Setup

Intuition Here:

- *1. Diminishing marginal benefit and increasing marginal cost of abatement investment*
- *2. Such asymmetry is further amplified by policy uncertainty*

A firm that solves a one-period problem of abatement:

- an abatement investment a; emission $e = \frac{\bar{e}}{\epsilon + a}$; pollution penalty τe
- External financing frictions: (1) an initial debt b
  (2) receives future financial cost -ϕ if binding $d \leqslant 0$
- Policy uncertainty: a pollution penalty $\tau \sim [0, \bar{\tau}]$ with pdf $\pi_\tau(\tau)$ and s.d. σ_τ

The firm's optimization: (define $\tilde{a} \equiv a$ as the direct cost of a)

$$\max_a \int_0^{\bar{\tau}} \left\{ \underbrace{[1 - b \overbrace{-\tilde{a}}^{\text{Cost}} \overbrace{-\tau e}^{\text{Benefit}}]}_{\text{Internal Fund: } d} + [\nu - \underbrace{\phi \cdot \mathbf{1}(d \leqslant 0)}_{\text{Costly External Financing}}] \right\} y \pi_\tau(\tau) d\tau \tag{1}$$

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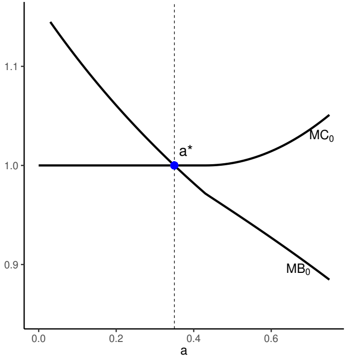
Mechanism: Unconstrained Firms

A cutoff $\hat{a}(\bar{\tau}, b)$ triggers the bindings of external financing friction $c = 0$

An unconstrained firm that has low initial debt b_u: $\rightarrow$ high cutoff $\hat{a}_u(\bar{\tau}, b_u)$

- an optimal abatement investment: $a_u^* < \hat{a}_u(\bar{\tau}, b_u)$
- a linear marginal cost: $MC_{a<\hat{a}_u(\bar{\tau}, b_u)} = 1$
- a downward sloping marginal benefit: $MB_{a<\hat{a}_u(\bar{\tau}, b_u)} = -E[\tau]\frac{de}{da} = \frac{\bar{e}E[\tau]}{(\epsilon+a)^2}$



Mechanism: Constrained Firms

A constrained firm that has high initial debt b_c: $\rightarrow$ low cutoff $\hat{a}_c(\bar{\tau}, b_c)$

- an optimal abatement investment: $a_c^* > \hat{a}_c(\bar{\tau}, b_c)$
- there exists a cutoff $\hat{\tau} = \frac{1-b-\tilde{a}}{e}$ such that $d \leqslant 0$ if $\tau > \hat{\tau}$
- financial costs and benefits enter the MC and MB curves

$$MC = \underbrace{1}_{\text{direct cost}} + \underbrace{(-\phi)\frac{\pi_\tau(\hat{\tau})}{1-\Pi_\tau(\hat{\tau})}\frac{d\hat{\tau}}{d\tilde{a}}\frac{d\tilde{a}}{da}}_{\text{financial cost}} = 1 + \phi\frac{\pi_\tau(\hat{\tau})}{1-\Pi_\tau(\hat{\tau})}\frac{(\epsilon+a)}{\bar{e}}$$

$$MB = \underbrace{-E[\tau]\frac{de}{da}}_{\text{direct benefit}} + \underbrace{(-\phi)\frac{\pi_\tau(\hat{\tau})}{1-\Pi_\tau(\hat{\tau})}\frac{d\hat{\tau}}{de}\frac{de}{da}}_{\text{financial benefit}} = \frac{\bar{e}E[\tau]}{(\epsilon+a)^2} + \phi\frac{\pi_\tau(\hat{\tau})}{1-\Pi_\tau(\hat{\tau})}\frac{(1-b-a)}{\bar{e}}$$

- where $\frac{\pi_\tau(\hat{\tau})}{1-\Pi_\tau(\hat{\tau})}$ is the hazard rate of incurring $d < 0$, external financing cost ϕ
- the marginal financial cost increases in a
- the marginal financial benefit decreases in a and b

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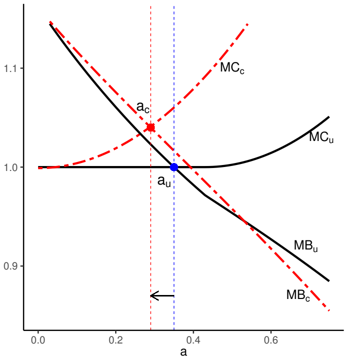
- the marginal financial cost increases in a
- the marginal financial benefit decreases in a and b

Mechanism: the Implication of Financial Frictions

Takeaways:

1. Financial cost and benefit asymmetry in abatement a $\rightarrow$ constrained $a_c^* \downarrow$
2. Higher initial debt further decreases financial benefit $\rightarrow$ constrained $a_c^* \downarrow$

Figure: **Abatement Investment Subject to Financial Frictions**

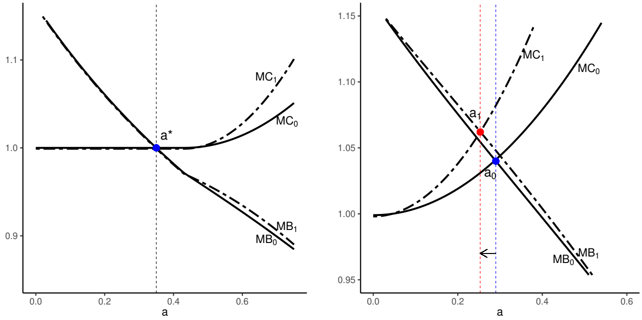


Mechanism: the Implication of Policy Uncertainty

The hazard rate $\frac{\pi_\tau(\hat{\tau})}{1-\Pi_\tau(\hat{\tau})}$ increases with σ_π (e.g., Arellano, Bai, Kehoe, 2019)

Takeaway: 3. Financial cost and benefit asymmetry in a enlarged $\rightarrow a_c^* \Downarrow$

Figure: **Abatement Investment Subject to Policy Uncertainty**



(a) Unconstrained Firm

(b) Constrained Firm

[Empirical Evidence]

Direct and supplementary evidence on the relationship between financial constraint, policy uncertainty, and abatement investment

Data and Measurements

Data Sources I: (pollution, abatement, and production at facility-level)

- Toxic Release Inventory (TRI) Database by the US Env'tl Protection Agency (EPA)
- Pollution Prevention (P2) Database, also from EPA
- National Establishment Time-Series (NETS) Database

Data Sources II: (financial constraint and policy uncertainty)

- CRSP, Compustat, and Others (BEA, BLS, FRED)
- Stateline Database and the CQ Election Electronic Library
- Textual Analysis of Firm-level Uncertainty by Hassan et al. (2019, 2020a, 2020b)

Connecting Data Sources: (facility-firm-state, 1991-2017)

- Abatement activities and pollution emissions at facility-level
- Financial constraint measures at firm-level
- Policy uncertainty measures at state or firm-level

Data: TRI | Data: P2 | Data: Waste Management Hierarchy

Data and Measurements

Measurement I: (pollution, abatement, and production at facility-level)

- Abatement activities: sum up the number of new source reduction activities across all chemicals in a year from the Pollution Prevention (P2) Database
- Pollution emissions: sum up the amounts (in pounds) of all chemicals released by a facility in a year from the Toxic Release Inventory (TRI) Database.

Measurement II: (financial constraint and policy uncertainty)

- Financial constraint: construct firm-level proxies as the WW and SA indexes of Whited and Wu (2006) and Hadlock and Pierce (2010) from CRSP/Compustat
- Policy uncertainty:
  - "close" gubernatorial elections as an increase of a facility's policy uncertainty following Akey (2015) and others
  - textual analysis on the topic of envr uncertainty in conference calls

Measure: WW and SA Measure: Summary

Empirical Analyses: Pollution Abatement Activities

Regression Specification: (Poisson and OLS)

$$x_{p,i,s,t+h} = \beta_1\, \sigma_{\tau|s,t} + \beta_2\, \sigma_{\tau|s,t} \times\, \eta_{i,s,t} + \beta_3\, \eta_{i,s,t} + \beta_4\, \Gamma_{i,s,t} + \beta_5 X_{s,t} + \beta_6 \mathtt{RepRatio}_{s,t} + \psi_p + \pi_t + \varepsilon_{p,i,s,t}, \tag{2}$$

- $x_{p,i,s,t+1 \to t+h}$: abatement by facility p in state s and belonging to parental firm i at from $t+1$ to next election $t+h$
- $\sigma_{\tau|s,t}$: " $= 1$" if the most recent state governor vote diff is within 5%; o/w " $= 0$"
- $\eta_{i,s,t}$: financial constraint of parental firm i in year t (WW and SA, standardized)
- $\Gamma_{i,s,t}$: firm-level controls (size, book-to-market, inv. rate, and ROA)
- $X_{s,t}$: state-level controls (local fundamentals)
- $\mathtt{RepRatio}_{s,t}$: number of Rep. wins over the past 4 gubernatorial elections
- ψ_p: facility fixed effects; π_t: time fixed effects; SE cluster at facility-level;

Empirical Analyses: Pollution Abatement Activities

Table: **Abatement Investment under Financial Frictions and Policy Uncertainty**

	Election-Based Uncertainty							
	Poisson				OLS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
σ_τ	0.00	0.01	-0.00	0.01	-0.00	-0.00	-0.00	-0.00
[t]	0.21	0.61	-0.05	0.38	-0.17	-0.12	-0.27	-0.25
WW	-0.01	-0.03			-0.01	-0.01		
[t]	-0.21	-0.66			-0.74	-1.46		
WW $\times$ σ_τ	-0.06	-0.06			-0.01	-0.01		
[t]	-3.70	-3.73			-2.86	-2.63		
SA			-0.19	-0.21			-0.05	-0.06
[t]			-4.41	-4.57			-4.46	-4.51
SA $\times$ σ_τ			-0.04	-0.04			-0.01	-0.01
[t]			-2.52	-2.61			-1.92	-1.70
Observations	91,433	89,990	93,096	91,351	149,882	148,130	152,272	150,150
Controls	No	Yes	No	Yes	No	Yes	No	Yes
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

- With respect to the economic significance: take SA measure in OLS, for example: If the SA index increases by one standard deviation:

1. Pollution abatement activities drop between 5% and 6%
2. With increased policy uncertainty, we find a further reduction of 1%

Empirical Analyses: Pollution Abatement Activities (Con'd)

	Text-Based Uncertainty							
	Poisson				OLS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
σ_τ	-0.02	-0.02	-0.02	-0.02	-0.00	-0.00	-0.00	-0.00
	(-1.71)	(-1.73)	(-1.71)	(-1.78)	(-1.13)	(-1.05)	(-0.91)	(-0.83)
WW	-0.10	-0.20			-0.01	-0.01		
	(-1.50)	(-2.52)			(-0.98)	(-1.35)		
WW $\times$ σ_τ	-0.03	-0.02			-0.00	-0.00		
	(-2.55)	(-2.43)			(-2.39)	(-2.39)		
SA			-0.44	-0.47			-0.06	-0.06
			(-4.21)	(-4.43)			(-3.85)	(-3.83)
SA $\times$ σ_τ			-0.03	-0.03			-0.00	-0.00
			(-2.91)	(-2.89)			(-2.25)	(-2.22)
Observations	25,575	25,487	25,793	25,689	64,142	63,968	64,679	64,464
Controls	No	Yes	No	Yes	No	Yes	No	Yes
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Empirical Analyses: Toxic Emissions

Regression Specification:

$$\begin{aligned} \log(1+E_{p,i,s,t+h}) = & \beta_1\, \sigma_{\tau|s,t} + \beta_2\, \sigma_{\tau|s,t} \times\, \eta_{i,s,t} + \beta_3\, \eta_{i,s,t} + \beta_4\, \Gamma_{i,s,t} \\ & + \beta_5 X_{s,t} + \beta_6 RepRatio_{s,t} + \psi_p + \pi_t + \varepsilon_{p,i,s,t}, \end{aligned} \tag{3}$$

- $E_{p,i,s,t+h}$: emission by facility p in state s and belonging to parental firm i from time $t+1$ to next tied election $t+h$
- $\sigma_{\tau|s,t}$: " $=1$" if the most recent state governor vote diff is within 5%; o/w " $=0$"
- $\eta_{i,s,t}$: financial constraint of parental firm i in year t (WW and SA, standardized)
- $\Gamma_{i,s,t}$: firm-level controls (size, book-to-market, inv. rate, and ROA)
- $X_{s,t}$: state-level controls (local fundamentals)
- $RepRatio_{s,t}$: the number of Rep. wins over the past 4 gubernatorial elections
- ψ_p: facility fixed effects; π_t: time fixed effects; SE cluster at facility-level;

Empirical Analyses: Toxic Emissions

Table: **Toxic Emissions under Financial Frictions and Policy Uncertainty**

	Election-Based				Text-Based			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
σ_τ	-0.03	-0.03	0.39	0.37	-0.01	-0.01	-0.01	-0.01
	(-0.95)	(-0.82)	(1.65)	(1.56)	(-1.06)	(-1.03)	(-1.39)	(-1.33)
WW	-0.06	-0.07			-0.01	-0.01		
	(-0.83)	(-0.73)			(-1.41)	(-1.04)		
WW $\times$ σ_τ	0.08	0.08			0.02	0.02		
	(2.46)	(2.46)			(2.56)	(2.62)		
SA			-0.13	-0.16			0.02	0.02
			(-1.57)	(-1.81)			(4.06)	(4.07)
SA $\times$ σ_τ			0.18	0.17			0.01	0.01
			(1.81)	(1.71)			(2.02)	(2.09)
Observations	112,894	111,893	114,746	113,649	64,280	64,142	65,028	64,853
R-squared	0.72	0.72	0.72	0.72	0.92	0.92	0.92	0.92
Controls	No	Yes	No	Yes	No	Yes	No	Yes
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Empirical Analyses: Debt Growth

Regression Specification:

$$\begin{aligned}\Delta \log B_{i,s,t+h} = \beta_1\ \sigma_{\tau|i,t} + \beta_2\ \sigma_{\tau|i,t} \times\ \eta_{i,t} + \beta_3\ \eta_{i,t} + \beta_4\ \Gamma_{i,t} \\ + \psi_{s,t} + \pi_t + \varepsilon_{i,t},\end{aligned} \tag{4}$$

- $\Delta \log B_{i,s,t+h}$: growth rate of total debt of firm i in state s from time $t+1$ to next election tied $t+h$
- $\sigma_{\tau|s,t}$: " $=1$" if the most recent state governor vote diff is within 5%; o/w " $=0$"
- $\eta_{i,s,t}$: financial constraint of parental firm i in year t (WW and SA, standardized)
- $\Gamma_{i,s,t}$: firm-level controls (size, book-to-market, inv. rate, ROA, lev., Tobin's q)
- $X_{s,t}$: state-level controls (local fundamentals)
- $\texttt{RepRatio}_{s,t}$: the number of Rep. wins over the past 4 gubernatorial elections
- ψ_p: facility fixed effects; π_t: time fixed effects; SE cluster at facility-level;

Empirical Analyses: Debt Growth

Table: **Debt Growth under Financial Frictions and Policy Uncertainty**

	Election-Based		Text-Based	
	(1)	**(2)**	**(3)**	**(4)**
σ_τ	-0.59	0.07	-0.87	-1.13
	(-0.19)	(0.02)	(-1.13)	(-1.40)
WW	-6.52		-15.87	
	(-1.92)		(-0.55)	
WW $\times$ σ_τ	-3.59		-1.71	
	(-1.23)		(-2.11)	
SA		1.41		-7.38
		(0.45)		(-1.11)
SA $\times$ σ_τ		-6.42		-1.57
		(-2.11)		(-2.00)
Observations	14,299	14,313	15,562	16,196
R-squared	0.15	0.15	0.26	0.27
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes

Robustness Checks and Remarks

Robustness checks:

- Alternative standard error cluster (state-level)
- Alternative abatement measures (unique pollution abatement activities)

Remarks:

- FC interacting with policy uncertainty dampen pollution abatement invt.
- Evidence from emission and debt growth supplements such a relation
- *(more tests to be done in the near future, comments welcomed!)*

Robustness: 1 Robustness: 2 Robustness: 3 Robustness: 4 Robustness: 5 Robustness: 6 Robustness: 7

[Quantitative Theory]
Could a model rationalize these findings and provide meaningful quantification and counterfactuals?

A Full-Blown GE Model

Heterogeneous Production w/ Pollution Firms:

- Produce and invest in both capital and abatement technology
- Face idiosyncratic productivity shocks and pollution penalty shocks
- Borrow subject to collateral constraints + non-negative dividend requirement

A General Equilibrium Block

- A family of representative households consumes and supplies labor
- Dis-utility of representative households from pollution emissions
- Aggregate capital and abatement technology producers

Policy Uncertainty Shocks

- MIT Shocks to the variance of the idiosyncratic pollution penalty shocks

Model: Setup | Model: Recursive Problem | Model: GE Block | Model: Prop. of FFs | Model: Prop. of PU

Model: Setup Back

Production and Finance: (Khan and Thomas, 2013)

- Production: $y_{jt} = z_{jt} k_{jt}^{\alpha}$, $\alpha < 1$ with $\log z_{jt+1} = \rho \log z_{jt} + \epsilon_{jt+1}$
- Finance: (1) collateral constraints $b' \leqslant \theta_k k$; (2) non-negative dividend $d_{jt} \geqslant 0$.

Pollution and Abatement:

- Emission: $e_{jt} = \frac{\bar{e}}{x_{jt}} z_{jt} k_{jt}^{\alpha}$, where $\bar{e}$ is the default level of emission intensity
- Abatement tech: $x_{jt+1} = (1 - \delta_x) x_{jt} + a_{jt+1}$, where δ_x is the depreciation
- Abatement investment: $a_{jt+1} \geqslant 0$

Environmental Policy Uncertainty:

- Pollution penalty: $\tau_{jt} e_{jt}$ (Shapiro and Walker, 2018)
- Idiosyncratic shock τ_{jt} i.i.d across firms following $\tau_{jt} \sim \mathrm{Lognormal}\,(\mu, \sigma)$
- Shocks to environmental policy uncertainty will be reflected in changes in σ_τ

Model: Recursive Problem Back

Net Worth Accumulation:

$$n = zk^{\alpha} + q_t(1-\delta)k - \tau e - (1+r_t)b \tag{5}$$

Continuing Equity Value Function: (Choices: $\{a', k', b'\}$)

$$v_t(z,x,n) = \pi_d \cdot \theta_n n + (1-\pi_d) \cdot \left\{ \max_{a',k',b'} d + \underbrace{\mathbf{E}_t}_{z',\tau'} \left[\Lambda_{t+1} v'(z',x',n') \right] \right\} \tag{6}$$

subject to

$$0 \leqslant d \leqslant n - a' - q_t k' + b' \tag{7}$$

$$b' \leqslant \theta_k k' \tag{8}$$

$$0 \leqslant a' \tag{9}$$

$$n' \equiv \max_{l'}\{z' k'^{\alpha} l'^{\nu} - w_{t+1} l'\} + q_{t+1}(1-\delta)k' - \tau' e' - (1+r_{t+1})b' \tag{10}$$

$$x' = (1-\delta_x)x + a' \tag{11}$$

where π_d is death rate, θ_n is death liquidation value, Λ_{t+1} is SDF.

Model: GE Block

Capital Good Producer: Profit maximization pins down the relative price of capital as

$$q_t = \frac{1}{\Phi'(I_t/K_t)} = \frac{I_t/K_t}{\delta}^{1/\phi} \tag{12}$$

Representative Household: (Choices: $\{C, L\}$)

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\gamma}}{1-\gamma} - \zeta E_t \right), \quad \text{s.t} \quad C_t + \frac{1}{1+r_t} B_t \leqslant B_{t-1} + \Pi_t$$

FOCs:

$$\Lambda_{t+1} = \beta \frac{U_c(C_{t+1}, L_{t+1})}{U_c(C_t, L_t)} = \beta \left(\frac{C_t + 1}{C_t} \right)^{-\gamma} \tag{13}$$

Parameterization

Table: : **Calibrated Parameter Values and Sources**

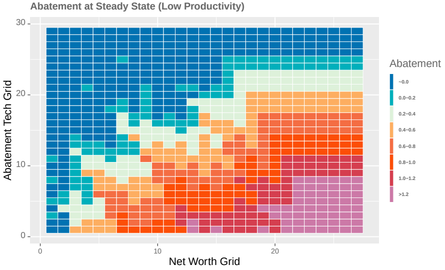
Symbols	Descriptions	Values	Sources
Fixed Parameters			
β	Discount factor	0.96	Annual Frequency
γ	Elasticity of intertemporal substitution	1.00	Logarithmic Utility
α	Capital share	0.65	DRS of Two-thirds
δ_k	Capital depreciation rate	0.10	Bachmann et al. (2013)
ϕ	Aggregate capital adjustment cost	4.00	Bachmann et al. (2013)
θ_d	Exit liquidation value	0.40	Kermani and Ma (2023)
Fitted Parameters			
ρ_z	Productivity persistence (fixed)	0.90	Targeted Moments
σ_z	Productivity volatility	0.03	Targeted Moments
π_d	Exogenous exit risk	0.087	Targeted Moments
n_0	Net worth of entry	1.20	Targeted Moments
θ_k	Collateral constraint	0.40	Targeted Moments
δ_x	Abatement technology depreciation rate	0.02	Targeted Moments
$\bar{e}$	Default pollution emission intensity	10.0	Targeted Moments
μ	Mean of pollution penalty	0.005	Targeted Moments
p_τ	Probability of no pollution penalty (normal)	0.40	Targeted Moments
σ	Volatility of pollution penalty (normal)	0.03	Targeted Moments
p_τ^h	Probability of no pollution penalty (elevated)	0.70	Targeted Moments
σ^h	Volatility of pollution penalty (elevated)	0.075	Targeted Moments

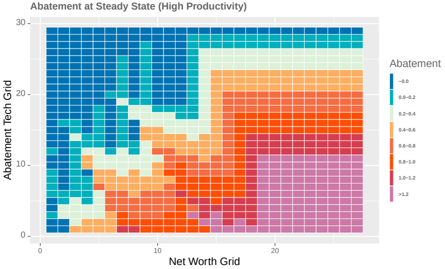
Moments Matching

Table: : **Targeted Moments: Model and Data**

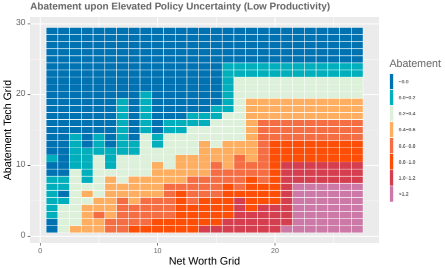
Moments	Data	Model
Output and Finance		
1-year autocorrelation of output	0.89	0.90
3-year autocorrelation of output	0.69	0.71
5-year autocorrelation of output	0.53	0.56
Size ratio of entrant relative to average	0.28	0.28
Annual exit rate of firms	0.09	0.09
Mean of debt/asset ratio	0.34	0.34
Pollution and Abatement		
Mean of emission intensity	5.38	4.16
Median of emission intensity	5.66	4.45
Standard deviation of emission intensity	3.05	1.82
P75/P25 of emission intensity	1.98	1.56
Ratio of zero pollution penalty	0.40	0.40
Mean of pollution penalty	0.02	0.02
Standard deviation of pollution penalty (normal)	0.02	0.02
Standard deviation of pollution penalty (elevated)	0.04	0.04

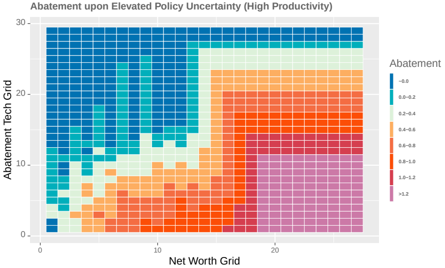
Abatement Policy at the Steady State





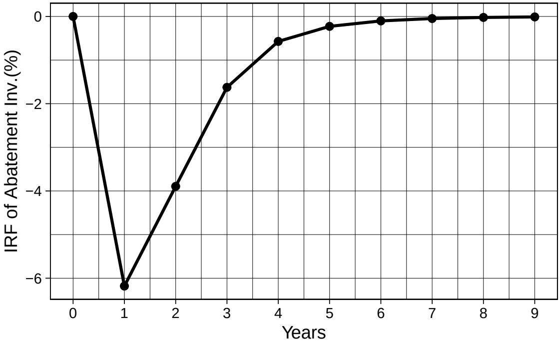
Abatement Policy upon Elevated Policy Uncertainty





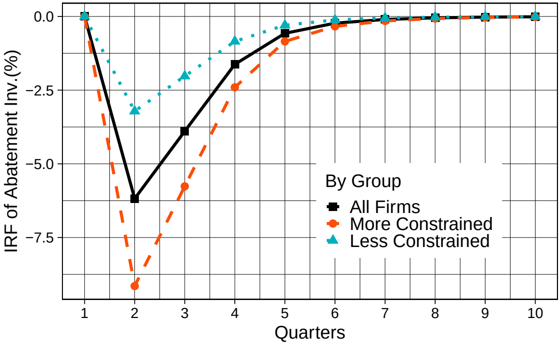
Impulse Responses to Policy Uncertainty Shocks

Figure: **Impulse Responses of Abatement Investment**



Impulse Responses to Policy Uncertainty Shocks

Figure: **Impulse Responses of Abatement Investment**



Conclusions and Next Steps

Conclusions for Now

- Effectiveness of environmental policy depends on FC and policy uncertainty
- Empirical evidence: higher FC $\times$ policy uncertainty $\rightarrow$ lower abatement
  (more tests to be done in the near future, comments welcomed!)
- Preliminary intuition in a simple model shows the mechanism
- Preliminary macro-finance model for quantification

Next Steps

- Explore more heterogeneity in the data/model
- More rigorous model simulated regressions or SMM
- Optimal policy decision under financial frictions and policy uncertainty
- A combination of financial policy and environmental policy

[Appendix]

Model: GE Block Back

Capital Good Producer: Profit maximization pins down the relative price of capital as

$$q_t = \frac{1}{\Phi'(I_t/K_t)} = \frac{I_t/K_t}{\delta}^{1/\phi} \quad (14)$$

Representative Household: (Choices: $\{C, L\}$)

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\gamma}}{1-\gamma} - \zeta E_t \right), \quad \text{s.t} \quad C_t + \frac{1}{1+r_t} B_t \leqslant B_{t-1} + \Pi_t$$

FOCs:

$$\Lambda_{t+1} \beta \frac{U_c(C_{t+1}, L_{t+1})}{U_c(C_t, L_t)} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \quad (15)$$

Model: Proposition 1 (FFs Matters) Back

Consider a firm at time t that is eligible to continue into the next period, has idiosyncratic productivity z, abatement technology x, and has a net worth n. Given $\{z, x\}$, the firm's optimal decision is characterized by one of the following cases.

(i) **Unconstrained:** there exists a threshold $\bar{n}(z,x)$ such that the firm is **financially unconstrained** if $n > \bar{n}(z,x)$. Unconstrained firms follow the "frictionless" capital accumulation policy $k'(z,x,n) = k'^*(z,x,n)$, the "frictionless" abatement investment policy $a'(z,x,n) = a'^*(z,x,n)$, the "frictionless" borrowing $b'^*(z,x,n) < \theta_k k'^*(z,x,n)$. For the optimal choices of $\{k'^*, a'^*, b'^*\}$ and any combination of realized shocks $\{z', \tau'\}$, **the next period optimal borrowing is not binding** $b''^*(z',x',n') < \theta_k k''^*(z',x',n')$.

(ii) **Constrained and Binding:** there exists a threshold $\underline{n}(z,x)$ such that the firm is **financially constrained and binding** if $n < \underline{n}(z,x)$. Constrained and binding firms follow the "binding" capital accumulation policy $k'(z,x,n) = k'^B(z,x,n)$, the "binding" abatement investment policy $a'(z,x,n) = a'^B(z,x,n)$, the "binding" borrowing $b'^B(z,x,n) = \theta_k k'^B(z,x,n)$.

(iii) **Constrained and Non-binding:** firms with $n \in [\underline{n}(z,x), \bar{n}(z,x)]$ such that the firm is **financially constrained and non-binding**. Constrained and non-binding firms follow the "constrained" capital accumulation policy $k'(z,x,n) = k'^C(z,x,n)$, the "constrained" abatement investment policy $a'(z,x,n) = a'^C(z,x,n)$, the "constrained" borrowing $b'^C(z,x,n) < \theta_k k'^C(z,x,n)$. A constrained and non-binding firm does not borrow up to collateral constraints to avoid binding situations in the future. That is, for the optimal choices of $\{k'^C, a'^C, b'^C\}$, there **exists** some combinations of realized shocks $\{z', \tau'\}$, **the next period optimal borrowing is binding** $b''^C(z',x',n') = \theta_k k''^C(z',x',n')$.

Model: Proposition 2 (PU Matters) Back

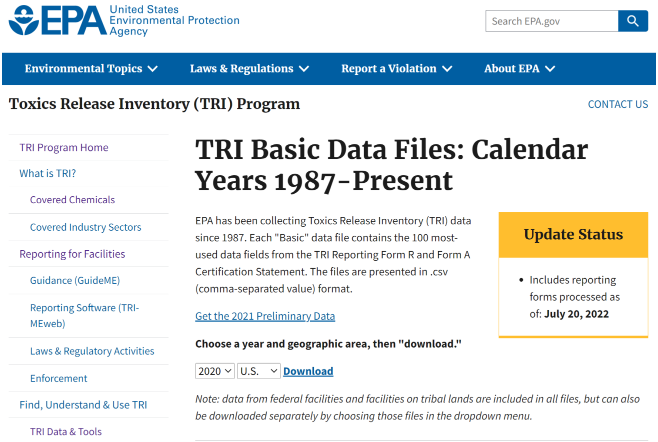
Consider a firm with the optimal decision in Proposition 1. When policy uncertainty in environmental regulation increases to σ_τ unexpectedly, the firm's optimal decision changes as follows.

(i) **Unconstrained:** the threshold $\bar{n}(z, x; \sigma_\tau)$ such that the firm is financially unconstrained if $n > \bar{n}(z, x; \sigma_\tau)$ increases with σ_τ. Unconstrained firms still follow the "frictionless" capital accumulation policy $k'(z, x, n) = k'^*(z, x, n)$, the "frictionless" abatement investment policy $a'(z, x, n) = a'^*(z, x, n)$, the "frictionless" borrowing $b'^*(z, x, n) < \theta_k k'^*(z, x, n)$. For the optimal choices of $\{k'^*, a'^*, b'^*\}$ and any combination of realized shocks $\{z', \tau'\}$, **the next period optimal borrowing is not binding** $b''^*(z', x', n') < \theta_k k''^*(z', x', n')$.

(ii) **Constrained and Binding:** the threshold $\underline{n}(z, x; \sigma_\tau)$ such that the firm is financially constrained and binding if $n < \underline{n}(z, x)$ decreases with σ_τ. Constrained and binding firms follow the "binding" capital accumulation policy $k'(z, x, n; \sigma_\tau) = k'^B(z, x, n; \sigma_\tau)$, the "binding" abatement investment policy $a'(z, x, n; \sigma_\tau) = a'^B(z, x, n; \sigma_\tau)$, the "binding" borrowing $b'^B(z, x, n; \sigma_\tau) = \theta_k k'^B(z, x, n; \sigma_\tau)$.

(iii) **Constrained and Non-binding:** firms with $n \in [\underline{n}(z, x; \sigma_\tau), \bar{n}(z, x; \sigma_\tau)]$ such that the firm is **financially constrained and non-binding**. Constrained and non-binding firms follow the "constrained" capital accumulation policy $k'(z, x, n; \sigma_\tau) = k'^C(z, x, n; \sigma_\tau)$, the "constrained" abatement investment policy $a'(z, x, n; \sigma_\tau) = a'^C(z, x, n; \sigma_\tau)$, the "constrained" borrowing $b'^C(z, x, n; \sigma_\tau) < \theta_k k'^C(z, x, n; \sigma_\tau)$. A constrained and non-binding firm does not borrow up to collateral constraints to avoid binding situations in the future. That is, for the optimal choices of $\{k'^C, a'^C, b'^C\}$, there **exists** some combinations of realized shocks $\{z', \tau'\}$, **the next period optimal borrowing is binding** $b''^C(z', x', n'; \sigma_\tau) = \theta_k k''^C(z', x', n'; \sigma_\tau)$.

Data: TRI Back

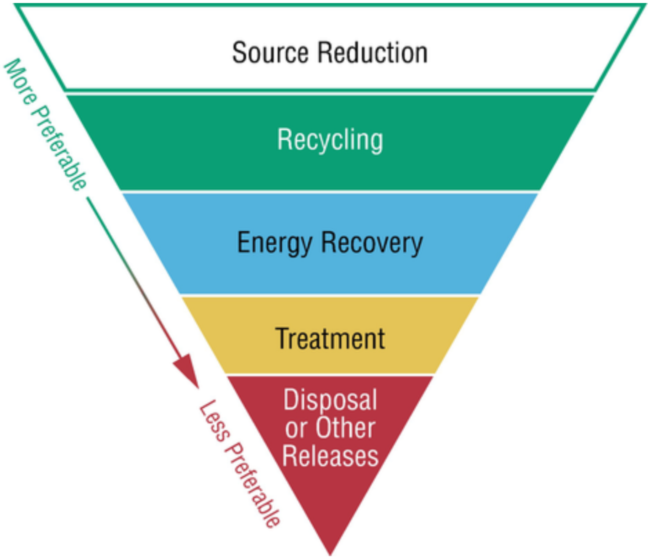


- `https://www.epa.gov/toxics-release-inventory-tri-program`

Data: P2 Back

- `https://www.epa.gov/toxics-release-inventory-tri-program`

Data: Waste Management Hierarchy Back



Measure: WW and SA Back

Details of constructions follows Farre-Mensa and Ljungqvist (2016)

Whited and Wu (2006):

- (1) based on the coefficients obtained from a structural model
- (2) measured as the projection of the shadow price of raising equity capital onto the following variables: cash flow to assets, a dummy capturing whether the firm pays a dividend, long-term debt to total assets, size, sales growth, and industry sales growth.

Hadlock and Pierce (2010): Size-Age (SA)

- (1) text-based approach from the 10-Ks of firms self-identifying as constrained
- (2) index based on size, size-squared, and age.

Measure: Summary Back

Table: : **Summary Statistics**

	Observations	Mean	Std	P5	P25	P50	P75	P95
	Panel A: Facility-level Characteristics							
Abatement Investment	152,621	0.85	3.38	0	0	0	0	4
Emissions	114,953	268,332.32	2,170,260	0.00	15.00	3,000.00	39,205.40	945,144.10
Sale (million)	152,610	144.03	467.00	2.20	13.73	38.19	105.76	562.43
Employment	70,260	575.51	1417.28	12	75	200	505	2,100
	Panel B: Firm-level Characteristics							
ME	17,420	8,256.96	28,726.94	34.4	279.57	1,141.84	4,510.44	33,896.93
B/M	17,362	0.66	0.67	0.15	0.33	0.52	0.81	1.54
I/K	17,295	0.19	0.12	0.06	0.11	0.16	0.23	0.41
ROA	17,391	0.13	0.09	0.01	0.09	0.13	0.17	0.26
Debt Growth (%)	15,741	5.42	74.62	-64.43	-15.45	-1.99	16.75	102.26
Leverage	17,400	0.25	0.16	0.00	0.13	0.25	0.36	0.54
Lease	17,411	0.29	0.21	0.00	0.13	0.27	0.42	0.67
q	16,291	1.67	1.17	0.84	1.09	1.38	1.88	3.38
WW	16,896	-0.35	0.10	-0.51	-0.42	-0.35	-0.28	-0.18
SA	17,425	-3.82	0.69	-4.64	-4.53	-3.85	-3.29	-2.65

Robustness 1 Back

Table: **Abatement Investment and Uncertainty Shocks**

	Poisson				OLS			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
σ_τ	0.00	0.01	-0.00	0.01	-0.00	-0.00	-0.00	-0.00
[t]	0.18	0.56	-0.05	0.35	-0.16	-0.12	-0.24	-0.23
WW	-0.01	-0.03			-0.01	-0.01		
[t]	-0.17	-0.58			-0.52	-1.31		
WW $\times$ σ_τ	-0.06	-0.06			-0.01	-0.01		
[t]	-2.66	-2.73			-2.01	-1.96		
SA			-0.19	-0.21			-0.05	-0.06
[t]			-4.30	-4.78			-4.10	-4.30
SA $\times$ σ_τ			-0.04	-0.04			-0.01	-0.01
[t]			-1.96	-1.97			-1.39	-1.28
Observations	91,433	89,990	93,096	91,351	149,882	148,130	152,272	150,150
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robustness 2 Back

Table: **Abatement Investment and Textual-Based Uncertainty Shocks**

	Poisson				OLS			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
σ_τ	-0.02	-0.02	-0.02	-0.02	-0.00	-0.00	-0.00	-0.00
[t]	-1.71	-1.73	-1.71	-1.78	-1.13	-1.05	-0.91	-0.83
WW	-0.10	-0.20			-0.01	-0.01		
[t]	-1.50	-2.52			-0.98	-1.35		
WW $\times$ σ_τ	-0.03	-0.02			-0.01	-0.01		
[t]	-2.55	-2.43			-2.39	-2.39		
SA			-0.44	-0.47			-0.06	-0.06
[t]			-4.21	-4.43			-3.85	-3.83
SA $\times$ σ_τ			-0.03	-0.03			-0.00	-0.00
[t]			-2.91	-2.89			-2.25	-2.22
Observations	25,575	25,487	25,793	25,689	64,142	63,968	64,679	64,464
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robustness 3 Back

Table: **Abatement Investment and Textual-Based Uncertainty Shocks**

	Poisson				OLS			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
σ_τ	-0.02	-0.02	-0.02	-0.02	-0.00	-0.00	-0.00	-0.00
[t]	-2.24	-2.26	-2.27	-2.32	-1.37	-1.26	-1.09	-1.00
WW	-0.10	-0.20			-0.01	-0.01		
[t]	-1.31	-1.85			-0.85	-1.05		
WW $\times$ σ_τ	-0.03	-0.02			-0.01	-0.01		
[t]	-2.62	-2.50			-2.71	-2.67		
SA			-0.44	-0.47			-0.06	-0.06
[t]			-3.55	-3.68			-3.23	-3.28
SA $\times$ σ_τ			-0.03	-0.03			-0.01	-0.01
[t]			-2.88	-2.94			-2.20	-2.24
Observations	25,575	25,487	25,793	25,689	64,142	63,968	64,679	64,464
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robustness 4 Back

Table: **Abatement Investment (Alternative) and Uncertainty Shocks**

	Poisson				OLS			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
σ_τ	0.00	0.01	-0.00	0.00	-0.00	-0.00	-0.00	-0.00
[t]	0.13	0.57	-0.13	0.28	-0.30	-0.26	-0.37	-0.39
WW	-0.03	-0.04			-0.00	-0.01		
[t]	-0.80	-1.01			-0.73	-1.48		
WW $\times$ σ_τ	-0.04	-0.04			-0.01	-0.01		
[t]	-2.97	-3.01			-2.53	-2.29		
SA			-0.15	-0.17			-0.04	-0.04
[t]			-4.17	-4.23			-4.45	-4.61
SA $\times$ σ_τ			-0.03	-0.03			-0.00	-0.00
[t]			-2.01	-2.14			-1.48	-1.36
Observations	91,433	89,990	93,096	91,351	149,882	148,130	152,272	150,150
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robustness 5 Back

Table: **Abatement Investment (Alternative) and Uncertainty Shocks**

	Poisson				OLS			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
σ_τ	0.00	0.01	-0.00	0.00	-0.00	-0.00	-0.00	-0.00
[t]	0.11	0.52	-0.10	0.25	-0.27	-0.25	-0.33	-0.37
WW	-0.03	-0.04			-0.00	-0.01		
[t]	-0.67	-0.92			-0.54	-1.34		
WW $\times$ σ_τ	-0.04	-0.04			-0.01	-0.01		
[t]	-2.59	-2.67			-1.88	-1.72		
SA			-0.15	-0.17			-0.04	-0.04
[t]			-4.06	-4.29			-4.12	-4.37
SA $\times$ σ_τ			-0.03	-0.03			-0.00	-0.00
[t]			-1.76	-1.85			-1.19	-1.10
Observations	91,433	89,990	93,096	91,351	149,882	148,130	152,272	150,150
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robustness 6 Back

Table: **Abatement Investment (Alternative) and Textual-Based Uncertainty Shocks**

	Poisson				OLS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
σ_τ	-0.02	-0.02	-0.02	-0.02	-0.00	-0.00	-0.00	-0.00
[t]	-2.35	-2.35	-2.09	-2.12	-1.68	-1.64	-1.39	-1.33
WW	-0.06	-0.11			-0.00	-0.01		
[t]	-1.06	-1.44			-0.64	-0.89		
WW $\times$ σ_τ	-0.03	-0.02			-0.01	-0.01		
[t]	-2.57	-2.49			-2.23	-2.26		
SA			-0.31	-0.32			-0.04	-0.04
[t]			-3.33	-3.39			-3.37	-3.34
SA $\times$ σ_τ			-0.02	-0.02			-0.01	-0.01
[t]			-2.03	-2.01			-1.72	-1.69
Observations	25,575	25,487	25,793	25,689	64,142	63,968	64,679	64,464
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robustness 7 Back

Table: **Abatement Investment (Alternative) and Textual-Based Uncertainty Shocks**

	Poisson				OLS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
σ_τ	-0.02	-0.02	-0.02	-0.02	-0.00	-0.00	-0.00	-0.00
[t]	-2.98	-2.99	-2.69	-2.72	-1.95	-1.89	-1.63	-1.55
WW	-0.06	-0.11			-0.00	-0.01		
[t]	-0.85	-1.15			-0.53	-0.72		
WW $\times$ σ_τ	-0.03	-0.02			-0.01	-0.01		
[t]	-2.78	-2.64			-2.40	-2.42		
SA			-0.31	-0.32			-0.04	-0.04
[t]			-2.64	-2.74			-2.81	-2.92
SA $\times$ σ_τ			-0.02	-0.02			-0.01	-0.01
[t]			-2.06	-2.07			-1.68	-1.67
Observations	25,575	25,487	25,793	25,689	64,142	63,968	64,679	64,464
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes