Financial Frictions and Pollution Abatement Over the Life Cycle of Firms

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Motivation

- It is tough to motivate firms to do pollution abatement, especially smaller ones
  - Abatement is not profit-generating, but for avoiding regulatory/social-image penalties
  - Most abatement activities are operating costs (80% by EPA), which do not build into capital
  - The return to abatement scales with production; per unit cost is high if the firm is small

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  - This indicates joint roles played by the above properties:
    (1) penalty-avoiding, (2) non-collateralizability, and (3) increasing-return-to-scale
- This paper aims to evaluate the joint roles of these properties to see:
  1. Detailed mechanisms, aggregate outcomes, and welfare implications
  2. Design of environmental policies with financial interventions

Summary of the Paper

- **Empirical Evidence:** Pecking order of investment and abatement
  - Smaller, younger, or more constrained firms prefer capital investment to pollution abatement, generating smaller total emissions, but are much dirtier with high emission intensity
  - As they accumulate more net worth, their abatement accelerates and emission intensity reduces.

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- **Empirical Evidence:** Pecking order of investment and abatement
  - Smaller, younger, or more constrained firms prefer capital investment to pollution abatement, generating smaller total emissions, but are much dirtier with high emission intensity
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- **Quantitative Model:** GE heterogeneous firms with financial constraints
  - Formalize the joint link between abatement, investment, emission, and dirtiness
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  - Formalize the joint link between abatement, investment, emission, and dirtiness
  - Key mechanism: Tradeoff between growth and penalty with financial frictions (FFs)
- **Quantitative Implications:**
  - FFs make the economy 15% dirtier; mainly because of smaller and younger firms
  - FFs make regulation sub-optimal at any level: aggregate welfare gain 40% ↓.
  - Non-preferential green loans that require abatement expense certificates are: (1) mainly greenwashed, (2) but still very effective!

A Pecking Order of Pollution Abatement and Capital Investment

Data and Measurements

Data Sources: toxic emission, pollution abatement, env. litigation, and balance sheets

- Toxic Release Inventory (TRI) Database
- Pollution Prevention (P2) Database
- Enforcement and Compliance History Online (ECHO) system
- National Establishment Time-Series (NETS) Database → Aggregated to firm-level
- CRSP, Compustat, and others (BEA, BLS, FRED)

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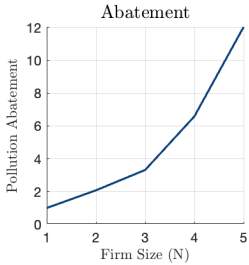
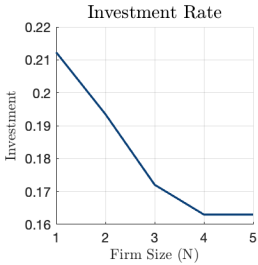
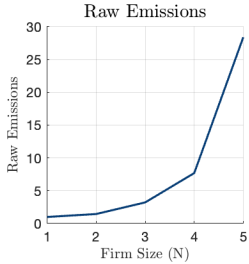
Variables of Interests:

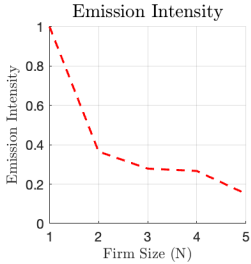
- Abatement: sum up the number of **new source reduction operating activities**
- Emission intensity: sum up raw emissions normalized by sales
- Financial constraints: total assets, property, plant, and equipment, age, and SA
- Other firm characteristics: sales, cash, Tobin's Q, etc

The Pecking Order of Abatement and Investment









The Pecking Order of Abatement and Investment

	(1) Log(Abate)	(2) Log(Emi.)	(3) Log(Emi./Sales)	(4) Inv. Rate
Panel A: Net Worth				
Log N	0.25***	0.85***	-0.84***	-0.02***
[t]	[3.55]	[5.93]	[-5.88]	[-2.59]
Panel B: Total Assets				
Log AT	0.24***	0.78***	-0.73***	-0.02***
[t]	[3.56]	[5.62]	[-5.17]	[-3.11]
Panel C: Capital				
Log K	0.26***	0.75***	-0.60***	-0.04***
[t]	[3.63]	[5.12]	[-4.18]	[-6.83]
Panel D: Employee				
Log EMP	0.25***	0.72***	-0.64***	-0.02***
[t]	[3.99]	[5.50]	[-4.99]	[-4.20]
Observations	8,873	18,497	18,484	19,718
R-squared	0.71	0.83	0.80	0.49

*Firm FE, Time FE, Cluster SE All Included

The Pecking Order of Abatement and Investment

Further Validations:

- Pecking Order on Size using Imputed Abatement Expenditures
- Pecking Order on Age using incorporation, WorldScope, and Compustat ages
- Pecking Order on Financial Indicators using Whited-Wu'06 and Hadlock-Pierce'10

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Additional Results:

- Peking Order in Two Dimensions (Consistent with the model)
- Pecking Order on Capital Investment related to Abatement

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Takeaway: Strong sorting of abatement, investment, total emission, and emission intensity over size, age, and other financial friction indicators (the life cycle of firm growth)

A GE Heterogeneous Firm Model of Pollution Abatement and Capital Investment under Financial Frictions

The Model Core on One Page

Production and Pollution

- Production: $y_{jt} = z_{jt} k_{jt}^{\alpha}$ | Pollution: $e_{jt} = y_{jt} \times \frac{\bar{e}}{1+\gamma a_{jt}}$ | Regulatory penalty: $\tau_{jt} e_{jt}$

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Financial Frictions and Decisions

- Collateral constraint: $b_{jt+1} \leq \theta k_{jt+1}$ | Cannot issue equity: $d_{jt+1} \geq 0$
- Choices: debt b_{jt+1}, capital k_{jt+1}, and abatement $a_{jt+1} \geq 0$

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Recursive Problem for Firms (π_d as exogenous exit risk)

$$v(z_{jt}, n_{jt}) = \max_{a_{jt+1}, k_{jt+1}, b_{jt+1}} d_{jt} + \mathbf{E_t}\Big\{\Lambda_{t,t+1}\Big[\pi_d n_{jt+1} + (1-\pi_d) v(z_{jt+1}, n_{jt+1})\Big]\Big\}$$

$$d_{jt} \equiv n_{jt} - k_{jt+1} - a_{jt+1} + \frac{b_{jt+1}}{1+r_t} \geq 0,$$

$$n_{jt+1} \equiv z_{jt+1} k_{jt+1}^{\alpha} + (1-\delta) k_{jt+1} - \tau_{jt+1} e_{jt+1} - b_{jt+1},$$

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Households Welfare

- $W_t = logC_t - \zeta logE_t$, ζ stands for disutility from pollution

Key Trade-offs with Financial Frictions

- Def: $\mu_t(z, n)$: Lagrange multiplier on collateral constraints
- Def: $\lambda_t(z, n)$: Lagrange multiplier on nonnegative dividend

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$$\underbrace{1+\lambda_t(z,n)}_{\text{marginal cost}} = \mathbf{E}_t\Bigg\{\Lambda'\Bigg[\left(\pi_d+(1-\pi_d)(1+\lambda_{t+1}(z',n'))\right) \times \underbrace{\left(\left(1-\frac{\tau'\bar{e}}{1+\gamma a'}\right)MPK(z',k')+(1-\delta)\right)}_{\text{[1.] marginal benefit from production}}\Bigg]\Bigg\} + \underbrace{\theta\mu_t(z,n)}_{\text{[2.] relax borrowing constraint}}$$

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- FOC for Pollution Abatement:

$$\underbrace{1+\lambda_t(z,n)}_{\text{marginal cost}} \geq \mathbf{E}_t\left\{\Lambda'\left[\left(\pi_d+(1-\pi_d)(1+\lambda_{t+1}(z',n'))\right)\right.\right.$$
$$\left.\left.\underbrace{\frac{\gamma\tau'\bar{e}}{(1+\gamma a')^2}z'k'^{\alpha}}_{\text{[3.] marginal benefit of abatement}}\right]\right\}$$

Key Trade-offs with Financial Frictions

- **Marginal Benefit of Capital Investment**
  1. Increase the production scale and generate more revenue
  2. Grow the firm's net worth and relax the borrowing constraint
  3. Larger production scale lowers the per-unit cost of abatement

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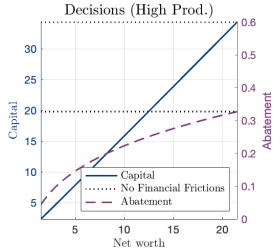
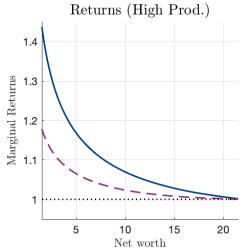
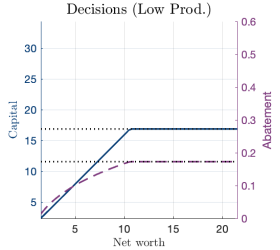
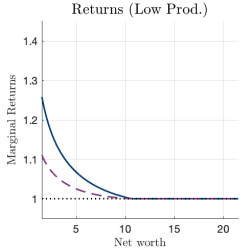
- **Marginal Benefit of Pollution Abatement**
  1. Lower the expected regulatory penalty on total emissions
- **Links to the Three Properties of Abatement**
  1. Penalty-avoiding: Firms have incentives to do operating abatement
  2. Non-collateralizability: Less attractive than capital investment when financially constrained
  3. Increasing-return-to-scale: Less attractive when production scale is small

Decision Rules: Investment vs Abatement

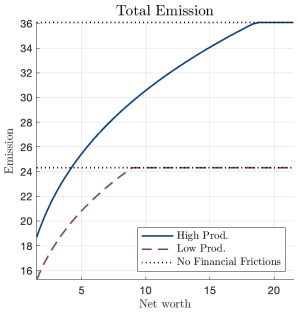


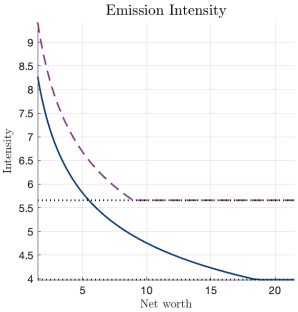




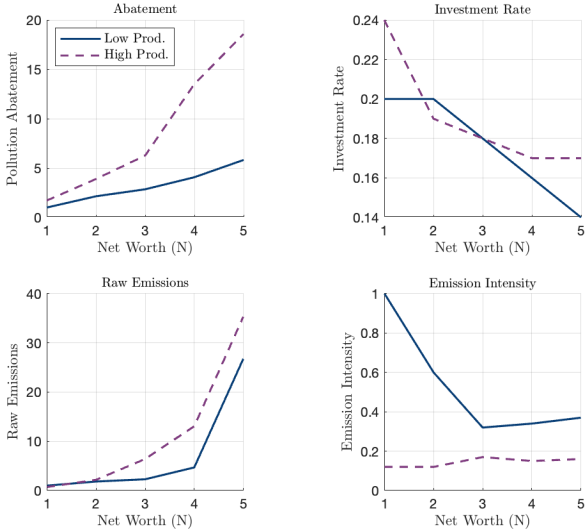


Decision Rules: Total Emission vs Emission Intensity





Decision Rules: Comparison with the Data



Validations of the Three Key Properties

1. Penalty-avoiding: Firms have incentives to do operating abatement
   - Firm-level data collected on environmental regulatory litigation
   - **Correlation:** Dirtier firms receive more litigation, and penalties scale with total emissions
   - We target the litigation moments in the following quantitative analysis

2. Non-collateralizability: Less attractive than capital investment when financially constrained
   - The quasi-natural event of the passage of anti-recharacterization laws
   - **Evidence:** Induced pollution abatement when collateral constraint is relaxed
   - More constrained firms significantly increase abatement more

3. Increasing-return-to-scale: Less attractive when production scale is small
   - The quasi-natural event of natural disasters destroying industry peers' factories
   - **Evidence:** Sales grows but emission intensity decreases
   - Firms significantly benefit more from the increasing returns to scale of abatement

Quantitative Analysis

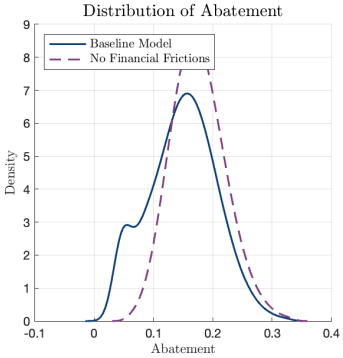
Parameterization

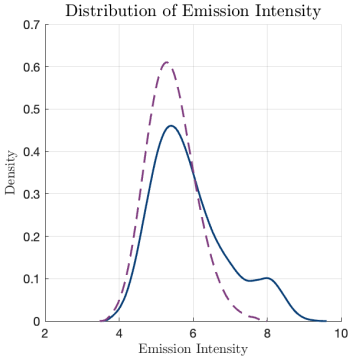
Symbols	Descriptions	Values	Sources
Fixed Parameters			
β	Discount factor	0.96	Annual Frequency
α	Capital share	0.55	DRS of Two-thirds
δ_k	Capital depreciation rate	0.10	BEA Data
ζ	Dis-utility of pollution emission	0.17	Uncalibrated
Fitted Parameters			
ρ_z	Productivity persistence (fixed)	0.90	Targeted Moments
σ_z	Productivity volatility	0.03	Targeted Moments
π_d	Exogenous exit risk	0.087	Targeted Moments
n_0	Net worth of entry	2.50	Targeted Moments
θ_k	Collateral constraint	0.40	Targeted Moments
$\bar{e}$	Highest emission intensity	10.0	Targeted Moments
γ	Elasticity of abatement into intensity	5.0	Targeted Moments
μ^τ	Mean of pollution penalty	0.01	Targeted Moments
σ^τ	Volatility of pollution penalty	0.01	Targeted Moments

Moments

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	0.01	0.01
Standard deviation of pollution penalty	0.01	0.01

Effects of Financial Frictions I: Distribution





Implication on Distribution:

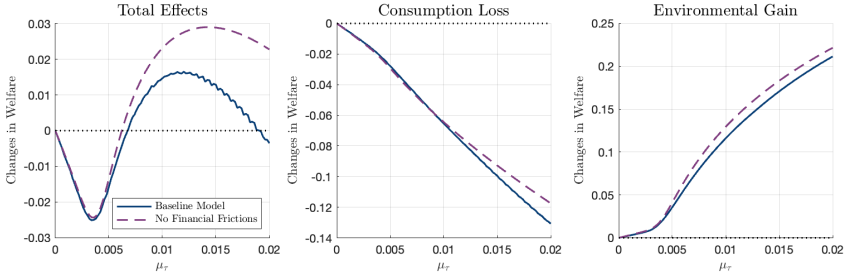
- Financial frictions inhibit firms from growing ⇒ Lower abatement
- Lower abatement ⇒ Higher emission intensity

Effects of Financial Frictions II: Aggregation

Outcomes	Output	Capital	Consump.	Abatement	Emission	Intensity
Frictionless	4.8	17.0	2.9	0.17	25.4	5.4
Baseline	4.0	13.2	2.6	0.14	23.1	6.2
% Changes	-20%	-29%	-12%	-21%	**-10%**	**+13%**

- Financial frictions inhibit firms from growing large and growing clean
  - Lower abatement ⇒ Higher emission intensity
  - Lower output ⇒ Lower total emission
  - Quantitatively speaking, the economy is about **13% dirtier**, though total emission is lower

Effects of Financial Frictions III: Optimal Regulation and Welfare



Optimal Penalty Implications:

- Off-setting between consumption loss and environmental gain
- A higher optimal penalty for the economy without financial frictions
- Aggregate gain of regulation policy is reduced by **about 40%** (3% vs 1.8%)

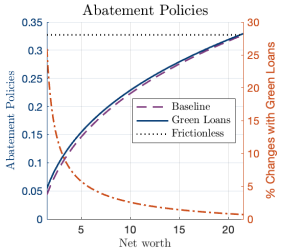
Green Loan Policy: Implementation

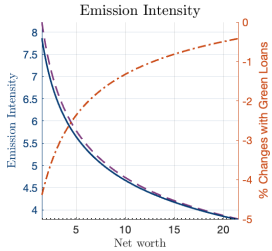
- A (tiny) green loan intervention by modifying the collateral constraint
- Commitment for the abatement as additional collateral for the green loan application
- The new collateral constraint with the case $\theta_a = 1$

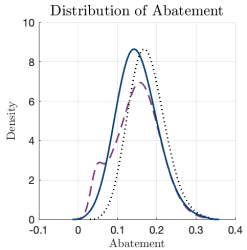
$$b_{jt+1} \leq \theta_k k_{jt+1} + \theta_a a_{jt+1}$$

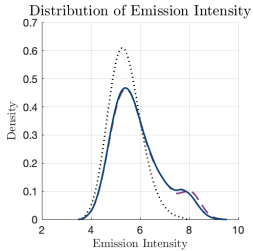
- **Policy Implications of Green Lending:**
  1. Relax financial frictions
  2. Moral hazard induced by green washing
  3. Overall quantitative assessment

Green Loan Policy: Decision Rules and Distributions









Green Loan Policy: Aggregate Effects

Panel A: Allocation of Green Loans

Outcomes	Total $\sum b$	Green $\sum b_g$	Used $\frac{\sum \Delta a}{\sum b_g}$	Washed $\frac{\sum \Delta k}{\sum b_g}$	New $\sum \theta_k \Delta k$
Baseline	5.30	0.00	–	–	–
Green Loan	5.37	0.04	0.002	0.038	0.03
% to Total $\sum b$	+1.32%	**+0.75%**	+0.04%	+0.71%	**+0.56%**
% to Green $\sum b_g$	–	–	**5%**	**95%**	**75%**

Panel B: Aggregate Effects of Green Loan Policies

Outcomes	Output	Capital	Consump.	Abatement	Emission	Emission Intensity
Baseline	4.04	13.25	2.58	0.137	23.14	6.16
Green Loan	4.06	13.32	2.59	0.139	23.11	6.12
% Changes	**+0.5%**	**+0.5%**	**+0.4%**	**+1.5%**	**-0.1%**	**-0.6%**

- The (tiny) green loan is quite effective, though mostly washed
- The gains are mainly from the constrained, smaller, and younger firms

Conclusion

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- Theory-guided empirical work on corporate environmental decisions
- Key findings:
  - Financial constraints significantly affect abatement investment
  - Constrained firms prioritize physical capital over abatement
- General equilibrium model to quantitatively account for:
  - Firm life-cycle patterns, the trade-off between investment and abatement
  - Substantially less welfare gain from regulation due to financial frictions
- Policy suggestions:
  - Credit intervention policies (works well even under imperfect monitoring)