Financial Frictions and Pollution Abatement Over the Life Cycle of Firms

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Nov.2025 @ HKUST

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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- How do the above properties affect firms' pollution abatement choices?
  - Our findings: Strong sorting of abatement, investment, total emission, and emission intensity over size, age, and other financial friction indicators (the life cycle of firm growth)

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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.

Summary of the Paper

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  - As they accumulate more net worth, their abatement accelerates and emission intensity reduces.
- **Quantitative Model:** GE heterogeneous firms with financial constraints
  - Formalize the joint link between abatement, investment, emission, and dirtiness
  - Key mechanism: Tradeoff between growth and penalty with financial frictions (FFs)

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  - 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!

Where Does the Paper Fit?

- **Environmental/Climate Macroeconomics and Policy Implications**
  1. GE of promoting the macroeconomic transition to cleaner inputs through taxes/subsidies
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  1. The effects of various financial conditions on emission intensity and total emission
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- **General Trade-offs of Corporate Policies and General CSR and ESG Practices**: Not Today!

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
- Environmental Expenditure (Refinitiv) 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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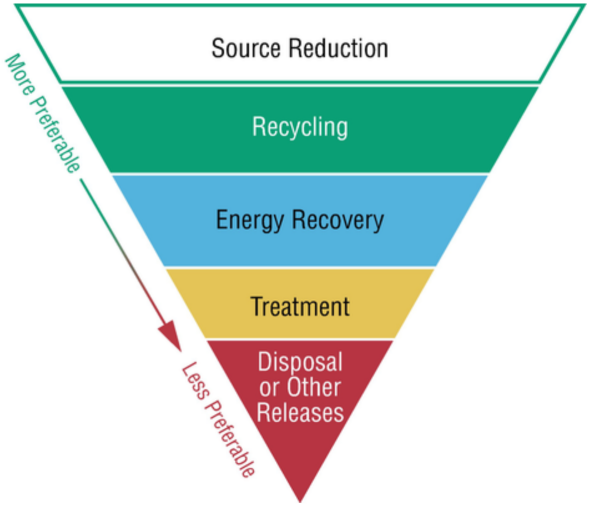
Variables of Interests:

- Abatement counts: sum up the number of **new source reduction operating activities**
- Abatement expenses: firm-level **environmental expenditure** of a subset of U.S. listed firms
- 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

Examples of Abatement Activities

Figure Waste Management Hierarchy



Examples of Abatement Activities

Table : The (Partial) List of Reported Abatement Activities

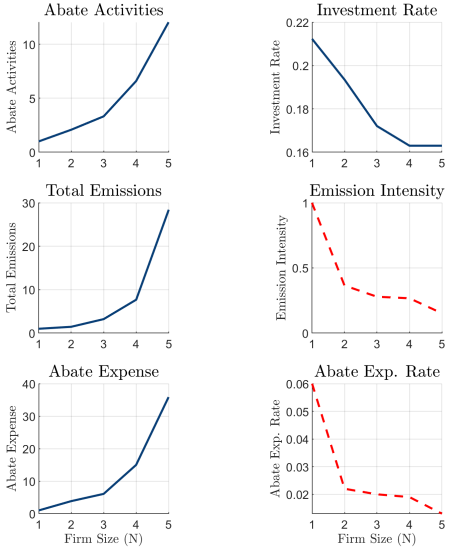
W Code	Catecgory	Abatement Activities	Score
W41	Raw Material Modifications	Increased purity of raw materials	9
W42	Raw Material Modifications	Substituted raw materials	10
W43	Raw Material Modifications	Substituted a feedstock or reagent chemical with adifferent chemical	9
W49	Raw Material Modifications	Other raw material modifications made	6
W81	Product Modifications	Changed product specifications	8
W82	Product Modifications	Modified design or composition of product	8
W83	Product Modifications	Modified packaging	10
W84	Product Modifications	Developed a new chemical product to replace a previous chemical product	4
W89	Product Modifications	Other product modifications made	7
W59	Cleaning and Degreasing	Modified stripping/cleaning equipment	3
W60	Cleaning and Degreasing	Changed to mechanical stripping/cleaning devices	2
W61	Cleaning and Degreasing	Changed to aqueous cleaners	10
W63	Cleaning and Degreasing	Modified containment procedures for cleaning units	9
W64	Cleaning and Degreasing	Improved draining procedures	10
W65	Cleaning and Degreasing	Redesigned parts racks to reduce drag out	7
W66	Cleaning and Degreasing	Modified or installed rinse systems	2
W67	Cleaning and Degreasing	Improved rinse equipment design	3
W68	Cleaning and Degreasing	Improved rinse equipment operation	8
W71	Cleaning and Degreasing	Other cleaning and degreasing modifications made	9

Data Summary

Table : Summary Statistics

	Mean	Std	P5	P25	Median	P75	P95	Observations
	CRSP-Compustat-TRI Merged Sample							
Abate Activities	3.70	13.06	0.00	0.00	0.00	2.50	16.50	20,518
Total Emissions	1,764,524	10,707,621	0.00	2,526.9	40,311	365,699	7,284,471	20,518
Emission/Sales	1,736.02	30,059.55	0.00	2.14	32.56	226.59	2,439.21	20,039
Investment/Capital (%)	18.35	11.56	5.49	10.98	15.99	22.49	39.71	20,401
Net Worth	9,564.39	31,055.2	83.82	489.85	1,781.65	6,627.39	3,9612.41	20,049
Total Assets	8,803.51	33,566.03	57.62	349.70	1,327.27	5,269.51	36,865.67	20,055
Fixed Capital	2,871.07	10,407.94	12.21	83.75	331.67	1,478.71	12,970.55	20,055
Number of Employees	18.60	68.51	0.30	1.57	4.90	14.40	73.53	20,438
Book-to-Market Ratio	0.65	0.66	0.14	0.32	0.52	0.81	1.55	20,448
Return on Asset	0.18	0.12	0.05	0.11	0.16	0.22	0.40	20,495
Leverage	0.26	0.16	0.00	0.14	0.25	0.37	0.54	20,473
	CRSP-Compustat-Refinitiv Merged Sample							
Abate Expense	173.01	1,121.68	0.11	3.64	19.76	70.19	644.9	3,212
Abate Expense/Capital (%)	8.98	246.98	0.01	0.15	0.57	1.73	6.82	3,135
Investment/Capital (%)	14.13	8.28	4.74	8.93	12.36	17.48	28.55	3,133
Net Worth	26,817.05	52,565.95	637.93	3,735.67	11,739.33	31,053.72	82,739.54	3,135
Total Asset	38,379.89	154,051.3	672.51	3,409.3	10,988.77	30,999.49	112,606.1	3,187
Fixed Capital	10,878.7	21,243.59	183.22	969.51	3781.4	12,340.64	39,115	3,135
Number of Employees	26.45	47.97	0.59	4.40	10.60	29.49	93.00	3,164
Book-to-Market Ratio	0.66	0.56	0.11	0.33	0.55	0.84	1.47	3,132
Return on Asset	0.12	0.11	0.01	0.08	0.12	0.16	0.26	3,139
Leverage	0.29	0.16	0.02	0.18	0.29	0.39	0.54	3,187

The Pecking Order of Abatement and Investment



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	CRSP-Compustat-TRI				CRSP-Compustat-Refinitiv	
	(1) Abate Activities	(2) Total Emissions	(3) Emission Intensity	(4) Inv. Rate	(5) Abate Exp.	(6) Abate Exp. Rate
	Panel A: Net Worth					
Net Worth	0.25***	0.85***	-0.84***	-0.02***	1.00***	-0.20
[t]	[3.55]	[5.93]	[-5.88]	[-2.59]	[3.74]	[-0.74]
Observations	8,899	18,545	18,535	19,770	3,003	3,003
R-squared	0.71	0.83	0.80	0.48	0.89	0.81
	Panel B: Total Assets					
Total Assets	0.24***	0.78***	-0.73***	-0.02***	0.97***	-0.37*
[t]	[3.56]	[5.62]	[-5.17]	[-3.11]	[4.07]	[-1.65]
Observations	8,906	18,568	18,554	19,792	3,055	3,005
R-squared	0.71	0.83	0.80	0.48	0.89	0.81
	Panel C: Fixed Capital					
Fixed Capital	0.26***	0.75***	-0.60***	-0.04***	1.00***	-0.72***
[t]	[3.63]	[5.12]	[-4.18]	[-6.83]	[4.59]	[-3.31]
Observations	8,906	18,567	18,554	19,792	3,005	3,005
R-squared	0.71	0.83	0.80	0.49	0.89	0.81
	Panel D: Number of Employees					
Number of Employees	0.25***	0.72***	-0.64***	-0.02***	1.27***	0.28
[t]	[3.99]	[5.50]	[-4.99]	[-4.20]	[3.79]	[0.67]
Observations	8,873	18,497	18,484	19,718	3,011	2,961
R-squared	0.71	0.83	0.80	0.49	0.89	0.81
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes

The Pecking Order of Abatement and Investment

Further Validations:

- Pecking Order on Size using Imputed Abatement Expenditures (Large sample)
- 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:

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- 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; Entry firms are relatively small)

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

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

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

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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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- FOC for Capital Investment:

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

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- FOC for Pollution Abatement:

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

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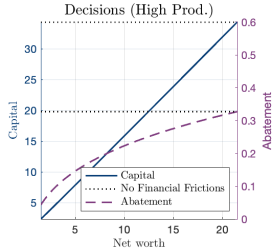
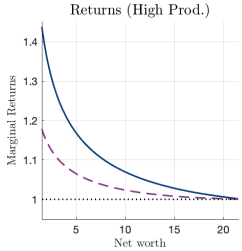
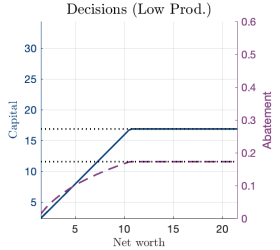
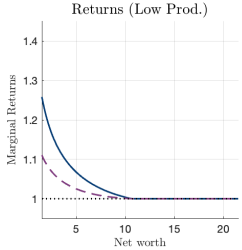
- **Marginal Benefit of Pollution Abatement**
  1. Lower the expected regulatory penalty on total emissions
- **Links to the Three Properties of Abatement**
  1. Penalty-avoiding: Firms have incentives to do operating abatement
  2. Non-collateralizability: Less attractive than capital investment when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

Decision Rules: Investment vs Abatement

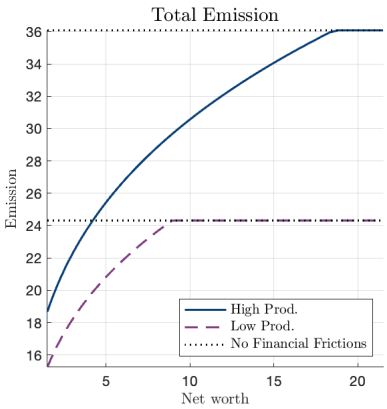


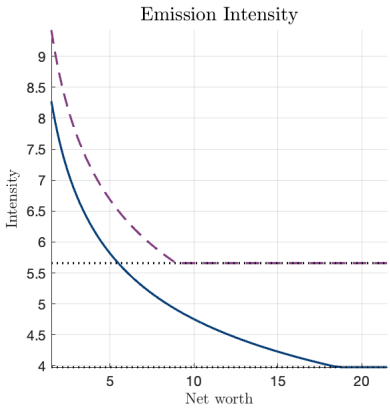




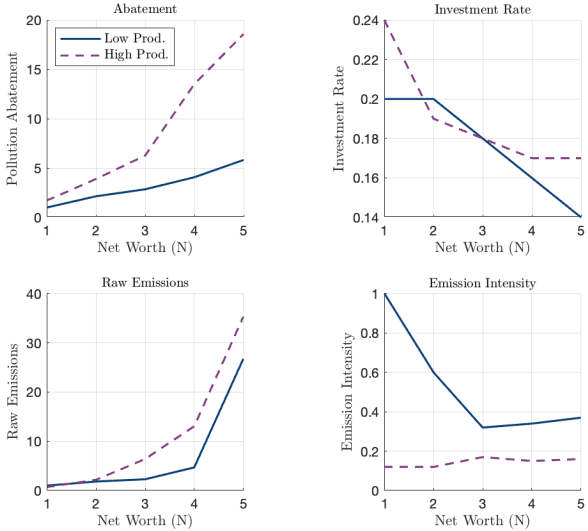


Decision Rules: Total Emission vs Emission Intensity





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

Validation I: Abatement to Avoid Penalty

- Firm-level data collected on environmental regulatory litigation
- **Correlation:** Dirtier firms receive more litigation, and penalties scale with total emissions

Table : **Predictive Regressions for Litigation**

	Probit				Poisson			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Production Emissions	0.41***				0.43***			
[t]	[3.30]				[2.88]			
Total Releases		0.51***				0.59***		
[t]		[3.54]				[3.56]		
Onsite Releases			0.49***				0.62***	
[t]			[3.34]				[3.83]	
Land Disposals				0.20***				0.33**
[t]				[2.60]				[2.26]
Observations	5,960	5,960	5,960	5,960	5,890	5,890	5,890	5,890
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Validation II: More Abatement When FFs are Relaxed

- The quasi-natural event of the passage of anti-recharacterization laws
- $o_{j,s,t} = \xi_j + \xi_t + b\,\text{Size}_{j,s,t} \times \text{Treat}_{s,t} + c\,\text{Controls}_{j,s,t} + \varepsilon_{j,s,t}$ (Use net worth as size)

Table : **Anti-recharacterization Laws and Abatement Dynamics**

	(1)	(2)	(3)	(4)
Size x Treat	-0.12**	-0.11**		
[t]	[-2.07]	[-2.06]		
$\text{Size}_{-2} \times \text{Treat}_{-2}$			-0.04	-0.04
[t]			[-1.04]	[-0.99]
$\text{Size}_{-1} \times \text{Treat}_{-1}$			-0.00	-0.01
[t]			[-0.09]	[-0.17]
$\text{Size}_{0} \times \text{Treat}_{0}$			-0.06	-0.07
[t]			[-1.33]	[-1.37]
$\text{Size}_{0} \times \text{Treat}_{1}$			-0.09*	-0.09*
[t]			[-1.78]	[-1.77]
$\text{Size}_{0} \times \text{Treat}_{2}$			-0.13**	-0.13**
[t]			[-2.21]	[-2.20]
$\text{Size}_{0} \times \text{Treat}_{3}$			-0.18***	-0.18***
[t]			[-3.02]	[-2.85]
Size	0.08	0.07	-0.14	-0.14
[t]	[0.76]	[0.64]	[-0.98]	[-0.96]
Observations	4,172	4,106	2,081	2,045
R-squared	0.80	0.80	0.83	0.83
Controls/FEs/Cluster	Yes	Yes	Yes	Yes

Validation III: Increasing-return-to-scale of Abatement

- The quasi-natural event of natural disasters destroying industry peers' factories
- $o_{j,i,t} = \xi_j + \xi_t + b \times \text{Demand}_{i,t} + c \times \text{Controls}_{j,i,t} + \varepsilon_{j,i,t}$
- Firms significantly benefit more from the increasing returns to scale of abatement

Table : **Effects of Demand Shocks on Sales and Emissions**

	(1)	(2)	(3)	(4)	(5)	(6)
	Sales Growth		**Emission Growth**		**Emission Intensity**	
Demand	3.01*	4.23***	-0.13	-0.09	-0.42***	-0.43***
[t]	[1.92]	[2.62]	[-0.92]	[-0.62]	[-3.05]	[-3.19]
Log (AT)		10.73***		0.03		0.22***
[t]		[4.42]		[0.19]		[3.35]
Log (Abate)		-0.27		0.06		-0.70***
[t]		[-0.40]		[1.14]		[-2.80]
B/M		-2.22***		-0.00		0.09**
[t]		[-4.11]		[-0.06]		[2.16]
I/K		1.45**		0.08*		-0.00
[t]		[2.41]		[1.87]		[-0.05]
ROA		8.08***		0.03		0.00
[t]		[11.83]		[0.59]		[0.05]
Observations	3,921	3,890	3,669	3,648	4,064	4,033
R-squared	0.30	0.40	0.13	0.13	0.86	0.87
Controls/FEs/Cluster	Yes	Yes	Yes	Yes	Yes	Yes

Quantitative Analysis

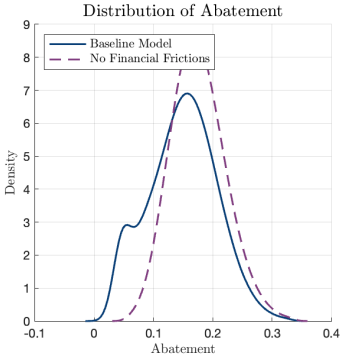
Parameterization

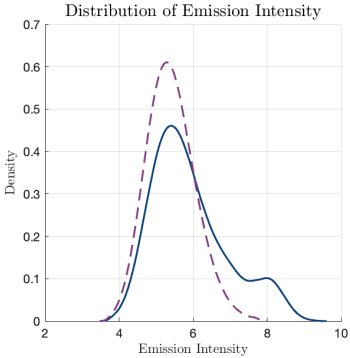
Symbols	Descriptions	Values	Sources
Fixed Parameters			
β	Discount factor	0.96	Annual Frequency
α	Capital share	0.55	DRS of Two-thirds
δ_k	Capital depreciation rate	0.10	BEA Data
ζ	Dis-utility of pollution emission	0.17	Uncalibrated
Fitted Parameters			
ρ_z	Productivity persistence (fixed)	0.90	Targeted 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
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:

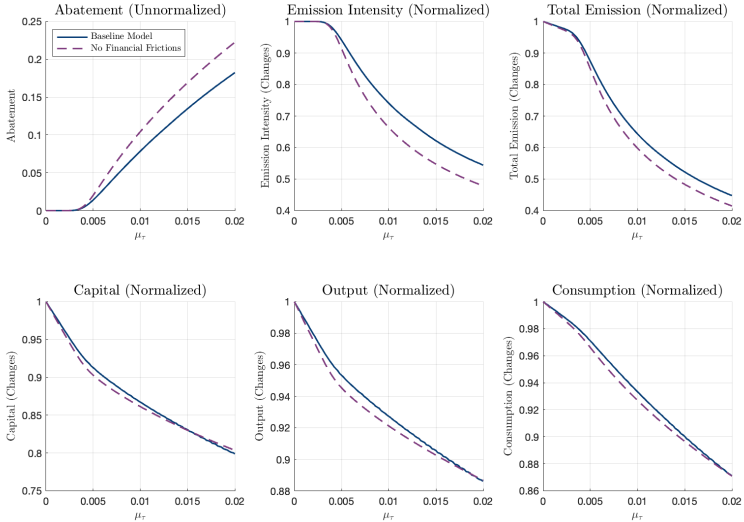
- Financial frictions inhibit firms from growing ⇒ Lower abatement
- Lower abatement ⇒ Higher emission intensity

Effects of Financial Frictions II: Aggregation

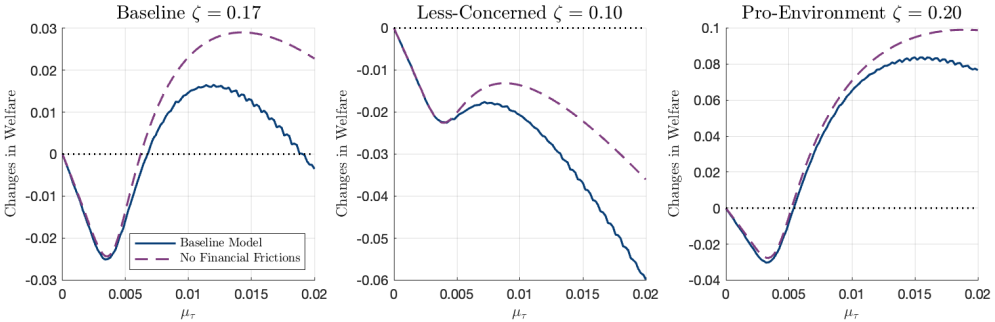
Outcomes	Output	Capital	Consump.	Abatement	Emission	Intensity
Frictionless	4.8	17.0	2.9	0.17	25.4	5.4
Baseline	4.0	13.2	2.6	0.14	23.1	6.2
% Changes	-20%	-29%	-12%	-21%	**-10%**	**+13%**

- 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

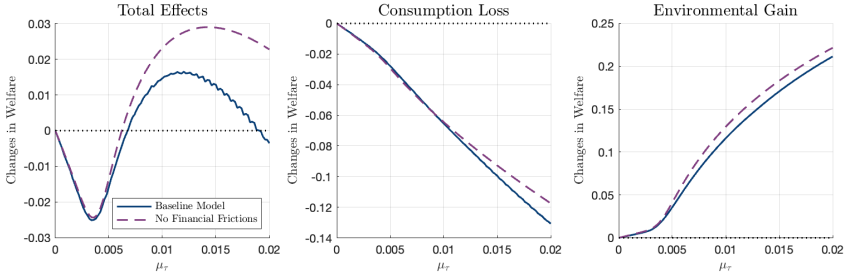
Effects of Financial Frictions III: The Role of Regulatory Penalty



Effects of Financial Frictions III: The Role of Preference



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%)

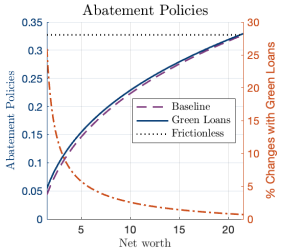
Green Loan Policy: Implementation

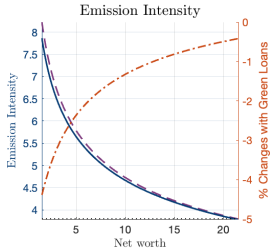
- A (tiny) green loan intervention by modifying the collateral constraint
- Commitment for the abatement as additional collateral for the green loan application
- The new collateral constraint with the case $\theta_a = 1$

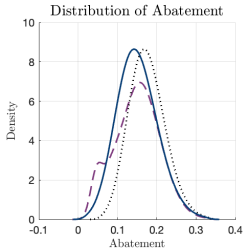
$$b_{jt+1} \leq \theta_k k_{jt+1} + \theta_a a_{jt+1}$$

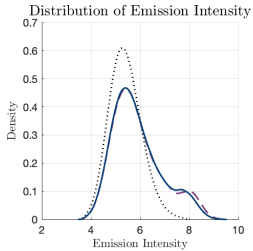
- **Policy Implications of Green Lending:**
  1. Relax financial frictions
  2. Moral hazard induced by green washing
  3. Overall quantitative assessment

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

Conclusion

- 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)