Prevention or cure? Abatement efficiency in a network technology

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Introduction

- Abatement activities generally fall into two categories: Prevention and Treatment.
- Most often these are combined into total abatement for environmental performance studies.
- We model prevention and treatment as separate linked technologies, allowing for reallocation of investment.
- Application to Swedish pulp and paper production, firm level panel 2002-2008.
- Across specifications, we find allowing reallocation increases potential production and abatement levels.
- Our results suggest greater relative importance of prevention at the margin.

Background

- We build on recent efforts to better capture the structural relationships governing pollution generation, production, and abatement using multi-stage, and/or network technology models (Färe et al., 2013; Hamph, 2014; Førsund, 20017a,b,c; Rødseth, 2017).
- We highlight a theoretical link between congestion and pollution-generating technology representations.
- Network framework could be widely applied to production processes that entail different abatement measures at different stages of production.
- Tradeoff in abatement measures is important from both a managerial and policy perspective
  - setting production targets and making longer term investment decisions within the firm
  - designing and targeting abatement incentives

Background

$$T_{JP} = \{(x,\ y,\ u) : x \text{ can produce } y \text{ and } u\},$$

Figure: Black box single process technology

Background

- Existing environmental production network studies include:
  - Murty et al. (2012) and Murty and Russell (2018) develop a bi-production technology, connecting conventional production axioms to a pollution-generating technology.
  - Färe et al. (2013) break the technology into a production stage and an abatement stage.
  - Hampf (2014) incorporates a materials balance condition into a similar two-stage network.
  - Rodseth (2017) formalizes axioms for materials balance and essentiality conditions.
- This study connects the production technologies for good and bad outputs through reallocation of pollution prevention and treatment activities.

Environmental Investments and Expenditures

- Environmental investments:
  - Pollution prevention processes (e.g., fuel switching/saving equipment and re-circulation of process gases)
  - Pollution treatment, or 'end-or-pipe' techniques (e.g., air filters and scrubbers)
  - Note, prevention measures can directly affect production of intended output, while treatment occurs post-production.
- Environmental expenditures:
  - Operating costs of existing environmental equipment, internal monitoring, personnel training, and remediation costs. (Juraite et al., 2014)
- We model optimal reallocation of prevention and treatment investments (x_I), given other input expenditures (x_E).

The Production Network Technology

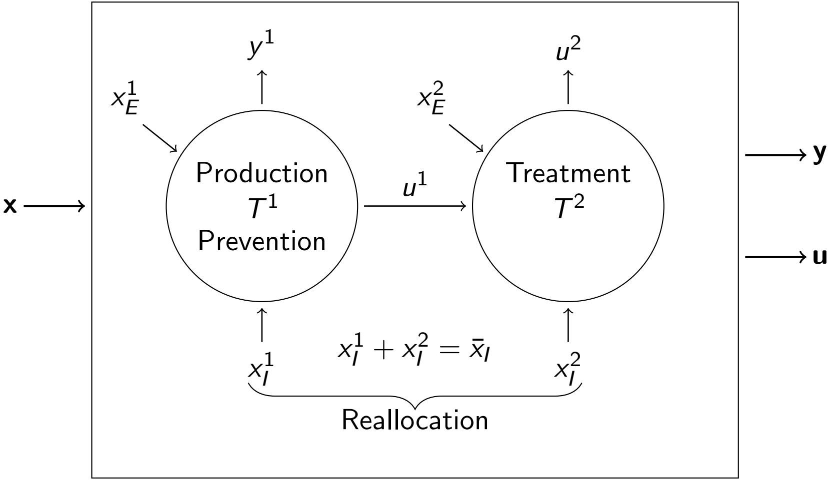
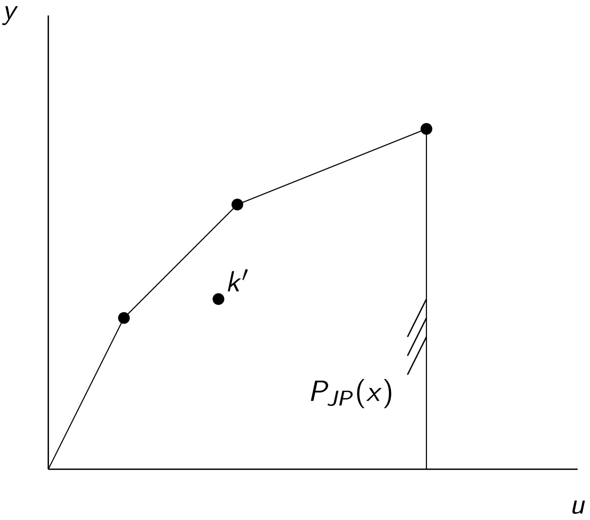


Figure: The Production Network Technology for Prevention and Treatment

Joint Production Pollution-Generating Technology

$$P_{JP}(x) = \{(y,\, u) : x \text{ can produce } y \text{ and } u\}\,,$$



Network Subtechnologies

- We break the single joint production technology into network of connected subtechnologies:
  - $$P^1(x^1) = \left\{(y^1,\ u^1) : x^1 \,\text{can produce}\, y^1 \,\text{and}\, u^1\right\}$$
  - $$P^2(x^2, u^1) = \left\{u^2 : u^1 \,\text{and}\, x^2 \,\text{can produce}\, u^2\right\}$$
- $P_{NW}(x^1, x^2, u^1) = P^1(x^1) \cap P^2(x^2, u^1)$.
- We estimate both the joint production and network technologies nonparametrically, using DEA.

Production and Abatement Efficiency

- We use the directional distance function to estimate the technology and measure efficiency.
- Joint production model:

$$\vec{D}_{O_{JP}}(x, y, u; g) = \max \{\beta : (y + \beta g_y, u - \beta g_u) \in P_{JP}(x)\}$$

- Network production model

$$\vec{D}_{O_{NW}}(x, y, u; g) = \max_{x^1, x^2} \{\beta : (y + \beta g_y, u - \beta g_u) \in P_{NW}(x^1, x^2, u^1)\}$$

- The directional vector, $\vec{g} = (g_y, g_u)$ specifies the joint expansion of intended output and contraction of unintended output.
- $\vec{D}_O = 0$ on the frontier, and $\vec{D}_O > 0$ increases with inefficiency.

Production and Abatement Efficiency

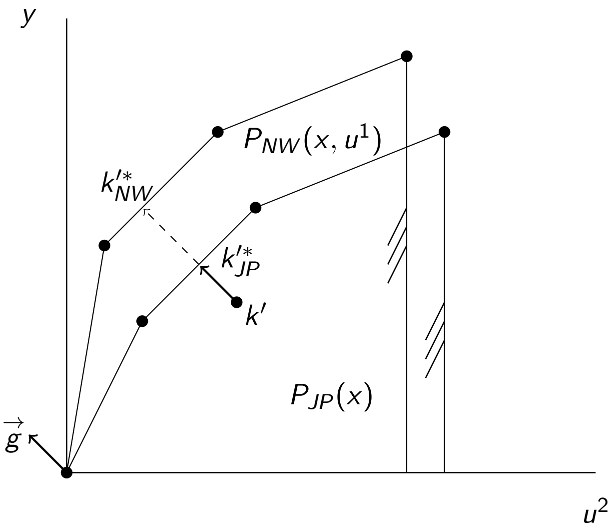


Figure: The directional output distance function and production frontier shift with reallocation

Production and Abatement Efficiency

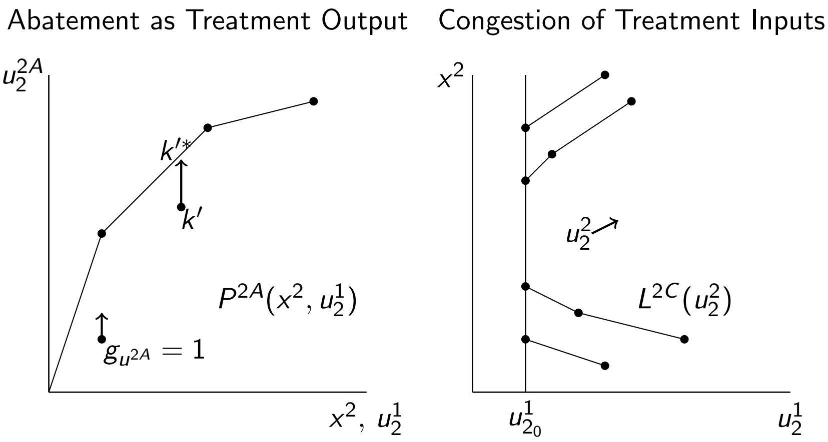


Figure: Alternative treatment stage models (i) Abatement as desirable output, (ii) Congestion of gross emissions and treatment input.

Application to Swedish Manufacturing Firms

We apply our prevention-treatment network model to Sweden's pulp and paper manufacturing sector, drawn from annual surveys conducted by Statistics Sweden for 2002-2008.

Our data includes at the plant level:

- Expenditures for standard production inputs and energy usage (coal, fuel oil, gasoline, natural gas)
- Investments in prevention and treatment capital, other environmental expenditures
- Emissions of CO_2 and SO_2
- Restrict to observations reporting positive values for prevention and/or treatment, yielding unbalanced panel of 42 firms

Application to Swedish Manufacturing Firms

Table: The Swedish pulp and paper sector production data, 2002-2008 (236 obs.)

Variable	Mean	Std. Dev.	Min	Max
Production (K SEK)	2,862,663	2,856,969	107,480	15,528,381
Labor (workers)	747.45	655.22	92.00	3,938.00
Capital (K SEK)	2,237,117	3,278,902	163	21,171,565
Fuel (MWH)	417,958	458,115	471	2,002,800
Electricity (MWH)	617,627	851,802	1,700	4,361,793
Prevention Inv. (SEK)	40,050	63,229	0.00	398,220
Treatment Inv. (SEK)	120,603	336,995	0.00	2,355,430
Total Env. Inv. (SEK)	160,654	335,313	482	2,355,430
Env. Exp. (SEK)	12,176	16,429	0.00	93,703
CO_2 (tonnes)	42,543	46,531	126	236,159
Gross SO_2 (tonnes)	168.96	185.42	0.32	879.26
Net SO_2 (tonnes)	63.84	72.21	0.04	353.19

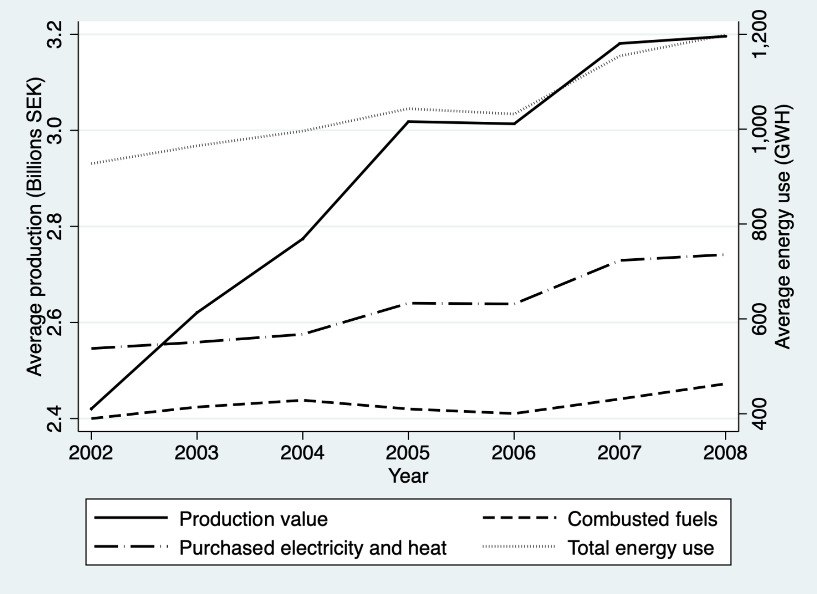


Figure: Annual average observed output and energy use

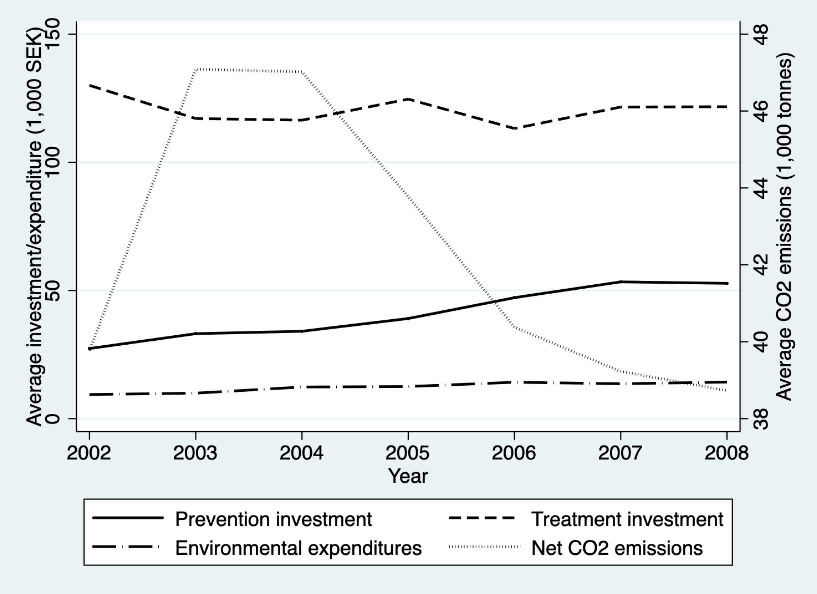


Figure: Annual average observed prevention and treatment investments and CO_2 emissions

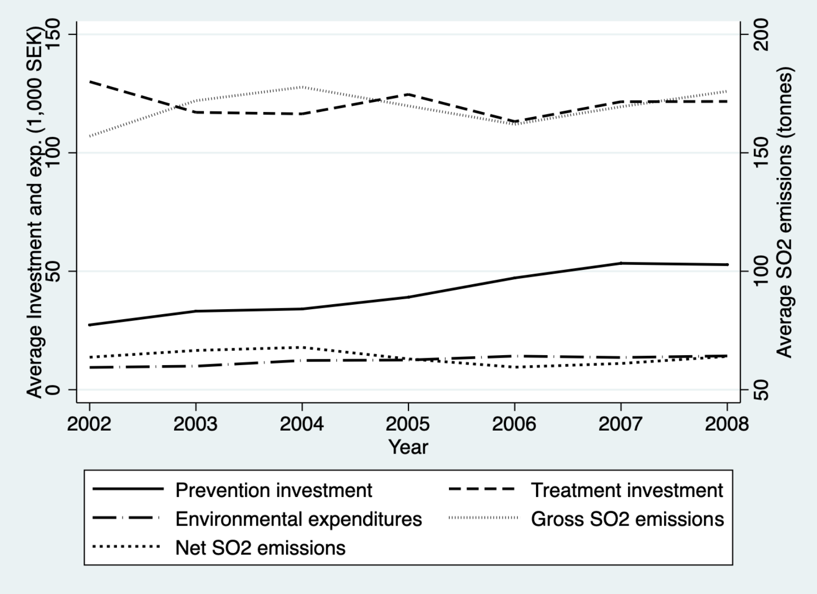


Figure: Annual average observed prevention and treatment investments and SO_2 emissions

Table: Inefficiency and investment reallocation results under alternative technology specifications

Variable	Mean	Std. Dev.	Min	Max
Inefficiency				
β Joint Production	0.088	0.224	0	1.742
β Abatement NW	0.133	0.270	0	1.806
β Congestion NW	0.143	0.288	0	1.914
Prevention Investment				
Observed	40,050	63,229	0	398,221
Optimal Abatement NW	41,537	57,440	0	398,229
Optimal Congestion NW	49,825	66,089	0	398,229
Treatment Investment				
Observed	120,603	336,995	0	2,355,430
Optimal Abatement NW	118,427	330,383	0	2,355,425
Optimal Congestion NW	110,480	331,500	0	2,355,425

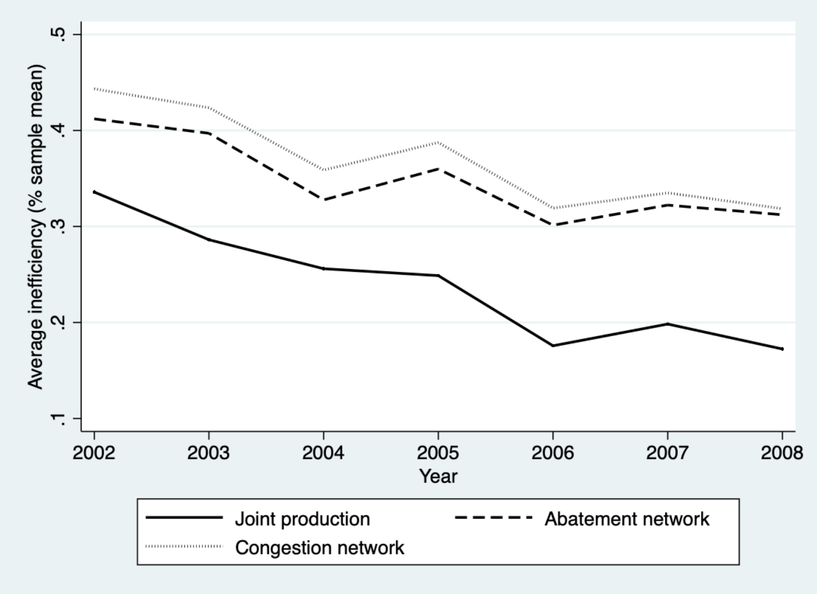


Figure: Industry Annual Share-weighted Average Inefficiency

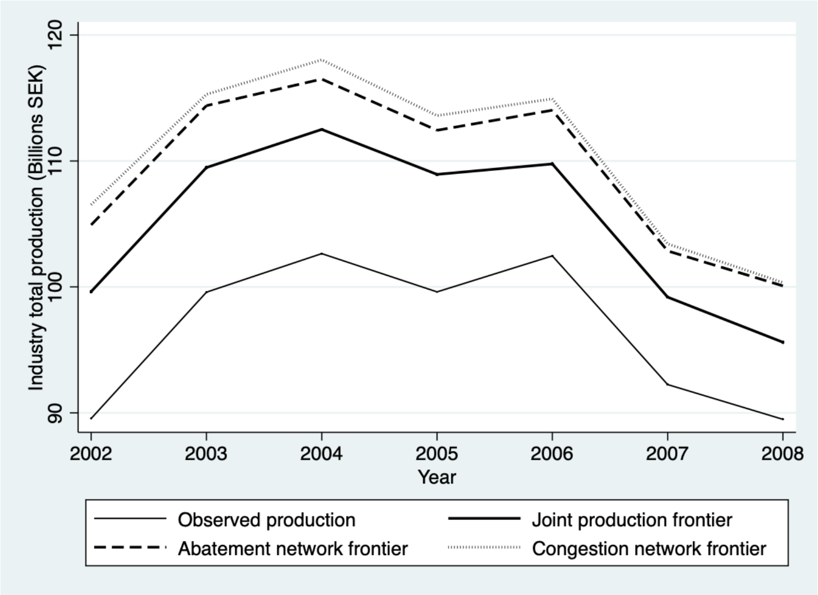


Figure: Annual industry total observed and frontier production under alternative technology models

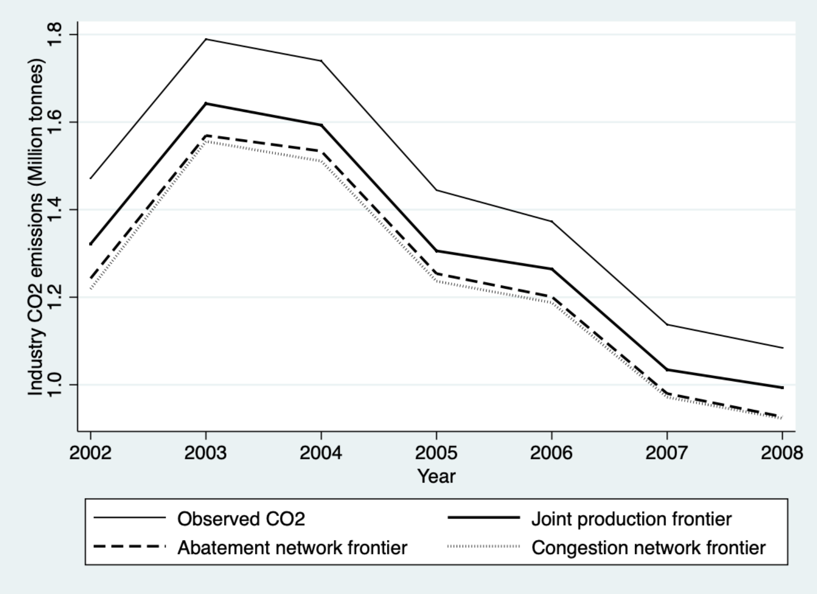


Figure: Annual industry total observed and frontier CO2 emissions under alternative technology models

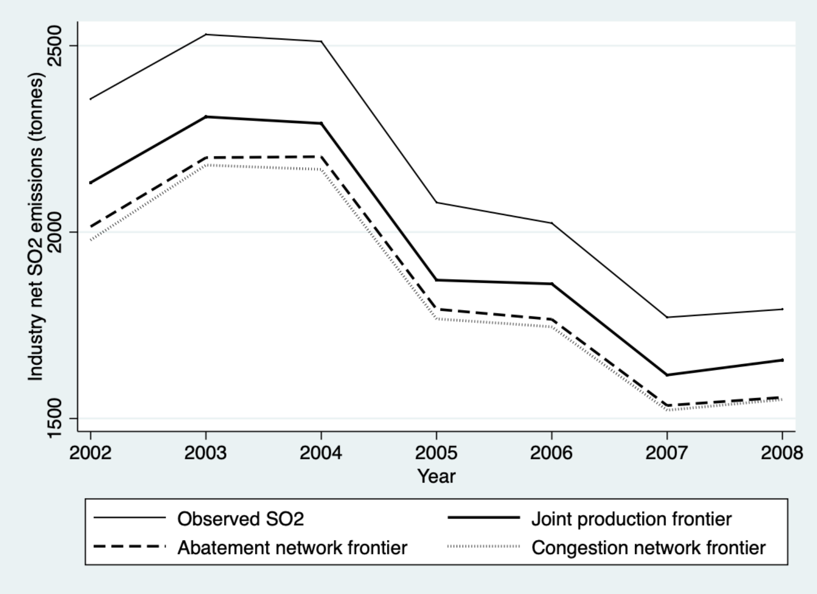


Figure: Annual industry total observed and frontier SO2 emissions under alternative technology models

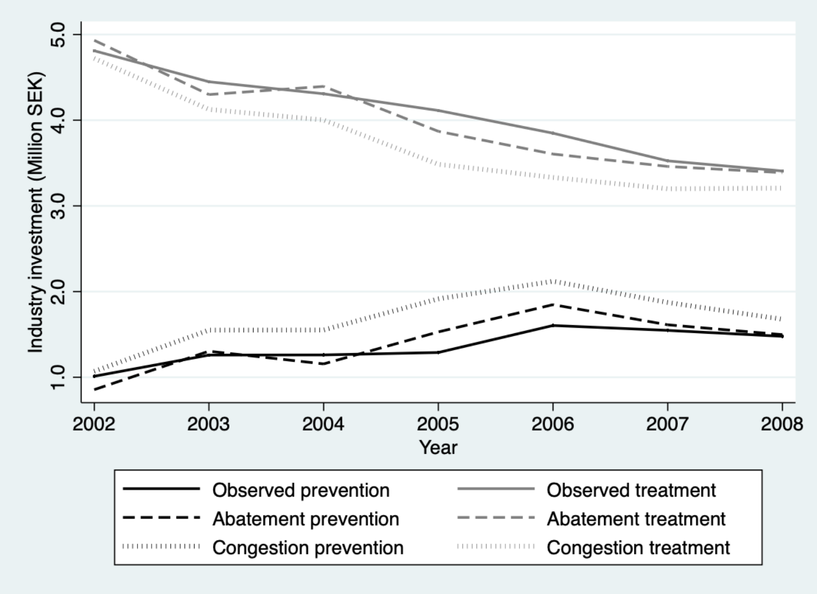


Figure: Industry annual total environmental investment, observed vs. optimal under alternative technology models

Table: Inefficiency and investment reallocation results under alternative technology specifications, industry-level simulation

Variable	Mean	Std. Dev.	(Comparison)
Inefficiency			
β Joint production	.088	.224	
β Abatement NW	.165	.338	**+24%**
β Congestion NW	.166	.337	**+16%**
Prevention Investment			
Observed	40,050	63,229	
Abatement NW	61,209	82,859	**+47%**
Congestion NW	60,902	82,047	**+22%**
Treatment Investment			
Observed	120,603	336,995	
Optimal Abatement NW	80,977	125,993	**-32%**
Optimal Congestion NW	72,267	176,835	**-35%**

Conclusion

Our main findings include:

- Allowing for intra-firm reallocation of prevention and treatment investment expands the overall production and abatement technology set
- On average, optimal shift from treatment to prevention
- Simulation results suggest additional potential gains from inter-firm reallocation
- For both application and simulation, congestion and abatement specifications yield similar results.
- For both the application and simulation, optimal total environment investment constraint non-binding.

Conclusion

- Key limitations include:
  - Analysis restricted to firms reporting positive values for prevention and/or treatment investment, loss of roughly 1/3 sample
  - Potential for mis-classification of investment types in data
  - Survey only reports final net emissions, requiring estimation of gross SO_2 from fuel combustion data
- Future extensions include multi-sector and multi-country analyses