

# Pollution Mitigation and Productivity: Evidence from Chinese Manufacturing Firms

Gautam Gowrisankaran<sup>1</sup> Michael Greenstone<sup>2</sup> Ali Hortaçsu<sup>3</sup>  
Mengdi Liu<sup>4</sup> Caixia Shen<sup>5</sup> Bing Zhang<sup>6</sup>

<sup>1</sup>University of Arizona, HEC Montreal and NBER

<sup>2</sup>University of Chicago and NBER

<sup>3</sup>University of Chicago and NBER

<sup>4</sup>University of International Business and Economics

<sup>5</sup>Shanghai University of Finance and Economics

<sup>6</sup>Nanjing University

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- As China has gotten richer, more demand/many policies to reduce pollution
- Pollution remains a huge problem in China
- May be costly to mitigate
- **Lessons are also valuable for other developing countries**

# Goals of this paper

- 1 To evaluate whether Chinese policies to lower pollution have been successful
- 2 To quantify the productivity cost of these policies for manufacturing firms



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  - Water pollutants: chemical oxygen demand (COD) and nitrogen-ammonia ( $\text{NH}_3\text{-N}$ )
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  - 0.63 CNY / KG of  $\text{SO}_2$
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  - 0.63 CNY / KG of  $\text{SO}_2$
  - 0.74 CNY / KG of COD
- By 2017, fees are very different across provinces:
  - Between 1.3 and 11 CNY / KG for  $\text{SO}_2$
  - Between 1.5 and 10.5 CNY / KG for COD

# Environmental regulation policy: discharge fees

Reasons for fee differences across provinces:

- Provinces were free to raise fees above national standards
- Some provinces did while nearby ones did not

# Air discharge fees

2006



2013





# Basic idea of our analysis

- We combine the following data:
  - 1 Firm/year level data on environmental discharges
  - 2 Chinese Annual Survey of Industrial Production data
  - 3 Provincial discharge fees



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- We document temporal and spatial variation in discharge fees
  - Substantial variation in increases in fees across provinces

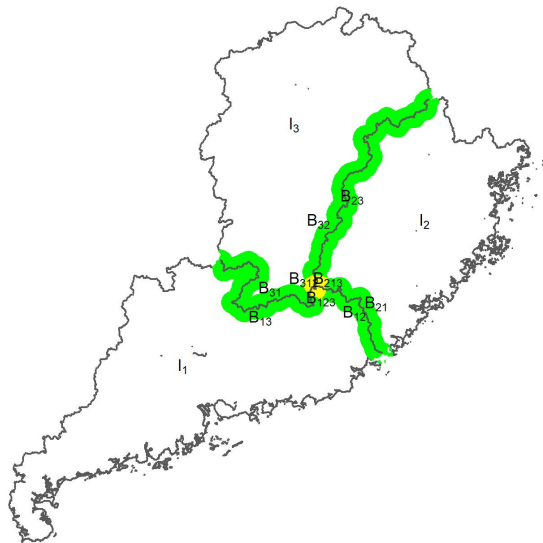
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- We document temporal and spatial variation in discharge fees
  - Substantial variation in increases in fees across provinces
- We evaluate impact of fees on:
  - Pollution output for four pollutants
  - Firm's productivity

# Sources of identification

- Use discontinuity based approach
  - Some provinces increased fees while nearby ones didn't
- Consider firms near border of provinces
  - Base results consider a 40KM band
- Further control for baseline effects of each province
  - Identification is a regression discontinuity in the difference-in-difference
  - Search for sharp *changes* on one side of border when fees increase
- Example: one region in sample is the Fujian-Guangdong border
  - Guangdong (but not Fujian) raised air fees from 0.6 to 1.2 and water fees from 0.7 to 1.4 in 2010
  - Allow for border area / year interactions
  - Allow for firm fixed effects or Fujian-near-border / Guangdong-near-border fixed effects
- Sample contains multiple such areas

# Example on three provinces



# Interpretation of map

- In this three province example, we there are 7 regions
  - This includes four border regions and three interior regions
  - Border regions are  $(B_{12}, B_{21})$ ,  $(B_{13}, B_{31})$ ,  $(B_{23}, B_{32})$ , and  $(B_{123}, B_{213}, B_{312})$
  - Interior regions are  $I_1$ ,  $I_2$ , and  $I_3$
- Map is based on Fujian, Guangdong, and Jiangxi provinces
  - But unlike map, the parts of those provinces near other provinces are separate regions
- We allow each region to have its own interaction with year
  - Each region within each province has a fixed effect (or we use firm fixed effects)
- Some specification use interior regions
  - Interior region times year fixed effects capture all fee changes
  - These regions help identify auxiliary parameters

# Data source 1: discharge fees

- We examined documents from Chinese province for the period 2003-15 by all pollutants
  - Collected discharge fees by pollutant/year/province
  - Effective collection of fees started in 2003
  - Greatest number of changes in 2010

## Data source 2: Environmental data

- Chinese Environmental Survey (CES), 2003-2015
  - Reports environmental discharges for manufacturing firms
- Derives from information collected the Chinese Ministry of Environmental Protection (MEP)
  - Most comprehensive environmental data in China
  - Only recently become accessible to researchers
  - Supposed to record 85% of water and air pollution

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  - Supposed to record 85% of water and air pollution
- Four recorded measures of pollution noted above
  - SO<sub>2</sub>: a major source of smog
  - NO<sub>x</sub>: another major source of smog
  - COD: an indicator of water pollution
  - NH<sub>3</sub>-N: another indicator of water pollution
  - Coal: fuel coal consumption
  - Oil: fuel oil consumption
  - Gas: natural gas consumption
  - Cost: operating costs of air/water abatement equipment
  - Number: number of air/water abatement equipment



# Sectors with most and least SO<sub>2</sub> pollution

Sector name	SO <sub>2</sub> rank	SO <sub>2</sub> discharge total	COD rank	COD discharge total
Nonmetal Mineral Products	1	21,908	12	479
Smelting & Pressing of Ferrous Metals	2	19,930	8	1,349
Raw Chemical Materials & Chemical Products	3	13,753	3	5,147
Smelting & Pressing of Nonferrous Metals	4	10,492	13	396
Petroleum Processing, Coking Products & Nuclear Fuel Processing	5	7,627	10	838
Papermaking & Paper Products	6	5,598	1	13,414
Textile Industry & Textile Clothes, Shoes & Caps Production	7	3,573	4	3,785
Major Grain & Sideline Food Processing	8	2,398	2	6,630
Food Production	9	1,468	6	1,467
Beverage Production	10	1,406	5	2,619
Tobacco Processing	24	145	25	48
Communications, Computer & Electric Equipment Manufacturing	25	111	14	350
Instruments, Meters & Clerical Machinery	26	77	26	43
Printing & Record Medium Reproduction	27	46	28	29
Furniture Manufacturing	28	36	29	26
Waste Resources & Waste Materials Recycling	29	34	30	20
Culture, Education & Sports Facilities	30	30	27	38

# Summary statistics

	Mean	Std.dev	75% Percentiles	25% Percentiles
SO2	120.79	929.77	51.2	4.05
NOx	71.54	629.42	17.16	1.4
COD	54.29	492.62	19.09	0.65
NH3-N	6.25	77.8	1.48	0.06
# of firms in sample	1,175,081			
# of firms we use	810,351			
Average tenure of firm	5.58			

## Data source 3: Firm production data

- Data from Annual Survey of Industrial Production (ASIP), 2003-2013
  - From annual surveys conducted by National Bureau of Statistics
  - Include firms with sales above 5 million RMB
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- We exclude data for 2010 and 2012, considered very unreliable

# Summary statistics

	Mean	Std.dev	75% Percentiles	25% Percentiles
Output	136217.7	1164171	82826	12639.02
Labor	257.8	921.89	268	56
Capital	34718.18	401470.6	15692.92	1707.99
# of firms in sample	3,167,734			
# of firms we use	2,558,737			
Average tenure of firm	4.75			

# Aggregate results

	Y = log Output			Y = log Labor			Y = log Capital		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Lagged In AirFee	0.142 (0.105)		0.202 (0.138)	0.149** (0.0616)		0.142 (0.0971)	0.204*** (0.0605)		0.168* (0.0836)
Lagged In WaterFee		0.00728 (0.164)	-0.141 (0.207)		0.120 (0.105)	0.0165 (0.146)		0.205* (0.108)	0.0822 (0.135)
Region*Year, Side-of-border, Industry*Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	30359	30359	30359	30271	30271	30271	30361	30361	30361
R <sup>2</sup>	0.770	0.770	0.770	0.758	0.758	0.758	0.735	0.735	0.735

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$



# Model

- In any year and region, firms faced with a technology
  - Two outputs: production revenue and pollution discharges
  - Three inputs: capital, labor, plus a TFP term
  - In logs,  $y$ ,  $d$ ,  $k$ ,  $l$ ,  $\omega$  respectively
- Allow for a revenue shock  $\varepsilon$ 
  - Can be due to variation in demand elasticity, for instance
- With a Cobb Douglas specification, we can write:

$$Y^{\tilde{\beta}_y} D^{\tilde{\beta}_d} = K^{\tilde{\beta}_k} L^{\tilde{\beta}_l} e^{\tilde{\omega}} e^{\tilde{\varepsilon}}$$

$$\Rightarrow y = \beta_k k + \beta_l l + \beta_d d + \omega + \varepsilon,$$

$$\text{where } \beta_k = \frac{\tilde{\beta}_k}{\tilde{\beta}_y}, \beta_l = \frac{\tilde{\beta}_l}{\tilde{\beta}_y}, \beta_d = -\frac{\tilde{\beta}_d}{\tilde{\beta}_y}, \omega = \frac{\tilde{\omega}}{\tilde{\beta}_y}, \varepsilon = \frac{\tilde{\varepsilon}}{\tilde{\beta}_y}$$

- Major goal of estimation is to evaluate production/pollution tradeoff,  $\beta_d$

# Empirical implementation of model

- 1 Reduced form regressions of revenue output on inputs and fees

$$y = \beta_k k + \beta_l l + \beta_f f + \omega + \varepsilon^y$$

- $f$  is the log of air or water (or both) fees
- $\omega$  includes a variety of fixed effects

- 2 Reduced form regressions of discharges on inputs and fees

$$d = \beta_f f + \omega + \varepsilon^d$$

- 3 OLS regressions of the production function given above
- 4 IV regressions of the production function given above
  - Fees instrument for discharge levels

Other details:

- Two-way cluster at province and year level

# Empirical implementation of model

- China has undergone a huge growth in productivity
- Accordingly, we let  $\omega$  be the sum of:
  - Year fixed effects (always)
  - Firm fixed effects (in many cases)
  - Region  $\times$  year interactions (in most cases)
  - Sector  $\times$  year interactions (in most cases)
  - Allows for different trends in productivity growth across regions and sectors

# Effects of air pollution fees on log SO<sub>2</sub>, 2003-2015

	(1) Entire Province	(2) Entire Province	(3) Entire Province	(4) Entire Province	(5) Border Only	(6) Border Only
In AirFee	-0.236** (0.0869)	-0.121** (0.0478)	-0.442*** (0.113)	-0.216** (0.0831)	-0.440*** (0.115)	-0.216** (0.0819)
Firm FE		Yes		Yes		Yes
Industry*Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Border FE	Yes					
Interior FE	Yes					
Side-of-Border FE	Yes		Yes		Yes	
Border*Year FE			Yes	Yes	Yes	Yes
Interior*Year FE			Yes	Yes		
Observations	810351	785264	810334	785244	276723	268375
R <sup>2</sup>	0.179	0.794	0.189	0.798	0.228	0.801

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

# Effects of air pollution fees on log coal consumption

	(1) Entire Province	(2) Entire Province	(3) Entire Province	(4) Entire Province	(5) Border Only	(6) Border Only
In AirFee	-0.134 (0.0910)	-0.0551 (0.0657)	-0.197* (0.102)	-0.0356 (0.0656)	-0.197* (0.105)	-0.0460 (0.0646)
Firm FE		Yes		Yes		Yes
Industry*Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Border FE	Yes					
Interior FE	Yes					
Side-of-Border FE	Yes		Yes		Yes	
Border*Year FE			Yes	Yes	Yes	Yes
Interior*Year FE			Yes	Yes		
Observations	1054702	1023637	1054677	1023608	338747	328720
R <sup>2</sup>	0.244	0.800	0.250	0.803	0.250	0.792

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

# Effects of air pollution fees on log oil consumption

	(1) Entire Province	(2) Entire Province	(3) Entire Province	(4) Entire Province	(5) Border Only	(6) Border Only
In AirFee	-0.0348 (0.0375)	-0.0125 (0.0221)	-0.0190 (0.0112)	-0.0132** (0.00521)	-0.0185* (0.00947)	-0.0154** (0.00631)
Firm FE		Yes		Yes		Yes
Industry*Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Border FE	Yes					
Interior FE	Yes					
Side-of-Border FE	Yes		Yes		Yes	
Border*Year FE			Yes	Yes	Yes	Yes
Interior*Year FE			Yes	Yes		
Observations	1054702	1023637	1054677	1023608	338747	328720
R <sup>2</sup>	0.0704	0.676	0.0802	0.681	0.0826	0.687

Standard errors in parentheses

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# Effects of air pollution fees on log natural gas consumption

	(1) Entire Province	(2) Entire Province	(3) Entire Province	(4) Entire Province	(5) Border Only	(6) Border Only
In AirFee	0.0497 (0.0329)	0.0470 (0.0370)	0.0195 (0.0523)	0.0675 (0.0575)	0.0159 (0.0498)	0.0653 (0.0567)
Firm FE		Yes		Yes		Yes
Industry*Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Border FE	Yes					
Interior FE	Yes					
Side-of-Border FE	Yes		Yes		Yes	
Border*Year FE			Yes	Yes	Yes	Yes
Interior*Year FE			Yes	Yes		
Observations	928545	888668	928522	888640	295430	282046
R <sup>2</sup>	0.0576	0.639	0.0618	0.642	0.0701	0.665

Standard errors in parentheses

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# Effects of water pollution fees on log COD, 2003-2015

	(1) Entire Province	(2) Entire Province	(3) Entire Province	(4) Entire Province	(5) Border Only	(6) Border Only
In WaterFee	-0.200** (0.0786)	-0.0874** (0.0366)	-0.0690 (0.112)	-0.0101 (0.0311)	-0.0600 (0.118)	-0.00404 (0.0280)
Firm FE		Yes		Yes		Yes
Industry*Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Border FE	Yes					
Interior FE	Yes					
Side-of-Border FE	Yes		Yes		Yes	
Border*Year FE			Yes	Yes	Yes	Yes
Interior*Year FE			Yes	Yes		
Observations	771089	745593	771059	745563	238449	229945
R <sup>2</sup>	0.205	0.795	0.213	0.800	0.244	0.805

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$



# Effects of air and water fees on log output, 2003-2013

	(1) Entire Province	(2) Entire Province	(3) Entire Province	(4) Entire Province	(5) Border Only	(6) Border Only
In AirFee	0.0745 (0.0612)	0.122 (0.0914)	0.157** (0.0550)	0.115* (0.0508)	0.153** (0.0552)	0.111* (0.0518)
In WaterFee	-0.151 (0.100)	-0.170 (0.110)	-0.221** (0.0824)	-0.0925 (0.106)	-0.219** (0.0826)	-0.0918 (0.109)
InL	0.465*** (0.0398)	0.348*** (0.0476)	0.469*** (0.0391)	0.353*** (0.0469)	0.468*** (0.0413)	0.348*** (0.0482)
InK	0.303*** (0.0195)	0.225*** (0.0201)	0.300*** (0.0197)	0.214*** (0.0190)	0.296*** (0.0220)	0.209*** (0.0214)
Firm FE		Yes		Yes		Yes
Industry*Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Border FE	Yes					
Interior FE	Yes					
Side-of-Border FE	Yes		Yes		Yes	
Border*Year FE			Yes	Yes	Yes	Yes
Interior*Year FE			Yes	Yes		
Observations	2490827	2400633	2490815	2400621	739139	708288
R <sup>2</sup>	0.608	0.855	0.614	0.861	0.617	0.864

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

# Heterogeneous effects of air and water fees on log output, 2003-2013

	(1) Entire Province	(2) Entire Province	(3) Entire Province	(4) Entire Province	(5) Border Only	(6) Border Only
<i>ln AirFee</i>	-0.0580 (0.222)	0.120 (0.173)	0.0951 (0.215)	0.194 (0.157)	0.229 (0.189)	0.189 (0.159)
<i>ln WaterFee</i>	0.998** (0.383)	0.843** (0.310)	0.837** (0.310)	0.820** (0.273)	0.111 (0.131)	0.176 (0.241)
<i>ln L</i>	0.169** (0.0660)	0.187** (0.0584)	0.148** (0.0639)	0.152** (0.0573)	0.173** (0.0594)	0.217*** (0.0480)
<i>ln K</i>	-0.313*** (0.0273)	-0.181*** (0.0371)	-0.313*** (0.0247)	-0.160*** (0.0323)	-0.294*** (0.0377)	-0.161*** (0.0350)
<i>ln L<sup>2</sup></i>	0.0387** (0.0125)	0.0300** (0.00897)	0.0399** (0.0124)	0.0326*** (0.00848)	0.0418** (0.0129)	0.0255** (0.00877)
<i>ln K<sup>2</sup></i>	0.0416*** (0.00391)	0.0312*** (0.00312)	0.0413*** (0.00389)	0.0292*** (0.00302)	0.0407*** (0.00443)	0.0288*** (0.00331)
<i>ln LK</i>	-0.0185 (0.0126)	-0.0208** (0.00864)	-0.0178 (0.0126)	-0.0201** (0.00863)	-0.0198 (0.0129)	-0.0179* (0.00919)
<i>ln L * lnAirFee</i>	0.0111 (0.0449)	-0.0330 (0.0273)	-0.00210 (0.0467)	-0.0504 (0.0314)	-0.0141 (0.0531)	-0.0541 (0.0374)
<i>ln K * lnAirFee</i>	0.00238 (0.00835)	0.0120 (0.00822)	0.00400 (0.00858)	0.0142 (0.00873)	-0.00167 (0.0144)	0.0192 (0.0120)
<i>ln L * lnWaterFee</i>	-0.217*** (0.0374)	-0.204*** (0.0315)	-0.225*** (0.0447)	-0.217*** (0.0438)	-0.117** (0.0491)	-0.134** (0.0553)
<i>ln K * lnWaterFee</i>	0.00779 (0.0199)	0.0182 (0.0213)	0.0143 (0.0212)	0.0296 (0.0243)	0.0291 (0.0231)	0.0488* (0.0261)
Firm FE		Yes		Yes		Yes
Industry*Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Border FE	Yes					
Interior FE	Yes					
Side-of-Border FE	Yes		Yes		Yes	
Border*Year FE			Yes	Yes	Yes	Yes

# Conclusion

- Chinese provinces started implementing pollution fees starting in 2003
  - This paper forms first look at these fees
- Fees appear to have lowered emitted pollution substantially
- Water fees appear to have lowered productivity
- No effect of air fees on lowering pollution
  - But, firms are switching fuels away from coal that may contribute to less pollution
- Heterogeneous impacts based on capital and labor
  - Fees appear to have increased the productivity of capital and lowered productivity of labor
  - Robust to relative usages of capital and labor