Pollution Mitigation and Productivity: Evidence from Chinese Power Plants

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December 18, 2020

Pollution in China

- China has experienced rapid economic growth over the past 20 years
  - But, a cost has been a big increase in pollution
- These two factors have led to demand in China to reduce pollution
  - Five year plans recognized pollution as a major problem in 2006
  - Environmental discharge fees started a couple of years before
- Despite these measures, pollution remains a huge problem in China:
  - Air and water pollution remain at very high levels
    - Vennemo et al. (2009), Jin et al. (2016), Zheng and Kahn (2017)
  - Pollution is seriously affecting health, longevity, and productivity of residents
    - Chen et al. (2013), Ebenstein (2012), Fu et al. (2017), Chang et al. (2016)
  - Substantial willingness to pay for lower pollution
    - Barwick et al. (2017), Ito and Zhang (2016)

Costs of pollution mitigation

- The fact that pollution remains a huge problem suggests it may be costly to mitigate
  - Greenstone (2002): U.S. Clean Air Act lowered output $75 billion over 15 years
  - Greenstone et al. (2012): CAA caused 4.8% drop in total factor productivity
- Tanaka et al. (2014) and Ankai (2016) find that *increases* in Chinese environmental stringency increased productivity
  - View supported by the "Porter hypothesis" (Porter and Van der Linde, 1995)
  - However, He et al. (2016) find the opposite to Tanaka et al.
- Important to understand *how* environmental regulations affect productivity
  - They may favor capital-intensive technologies over labor-intensive ones
  - They might cause high-emissions plants to mitigate their pollution
  - Or, they might simply cause these plants to exit/shrink output

Goals of this study

1. To understand impact of Chinese environmental discharge fees on lowering pollution
2. To quantify the productivity effects of the fee policy
3. To get at mechanisms of productivity effects, by decomposing the effects into parts based on within-firm changes, reallocation, entry, and exit

- We study power plants, which are by far the largest source of air pollution in China

Main approaches and challenges

- We exploit variation from fee changes in pollution prices in China
  - Chinese provinces started to assess discharge fees for SO_2 and NO_X in 2003
  - Substantial variation over time and province in fees
- We use detailed firm pollution emissions, input, and production data
- Also have ambient pollution data from monitors
- Main challenges:
  1. Reporting of pollution and production measures
  2. Endogeneity of fees

Relation to literature

Our study builds primarily on four literatures:

1. Tradeoffs between productivity and pollution
   - Greenstone (2002), Greenstone et al. (2012)
2. Determinants of firm productivity in China
   - Brandt et al. (2017), Roberts et al. (2017), Chen et al. (2020)
3. Impact of pollution reduction policies in China
   - Papers noted above, Liu et al. (2017), Karplus et al. (2018), Chang et al. (2019)
4. Productivity decompositions
   - Chandra et al. (2016), Eck (2020)

Outline of talk

Data sources used in study

The study combines data from four main sources:

1. Environmental discharge fees
2. Ambient pollution data
3. Chinese Environmental Survey (CES) firm pollution discharge survey
4. Annual Survey of Industrial Production (ASIP) firm production data

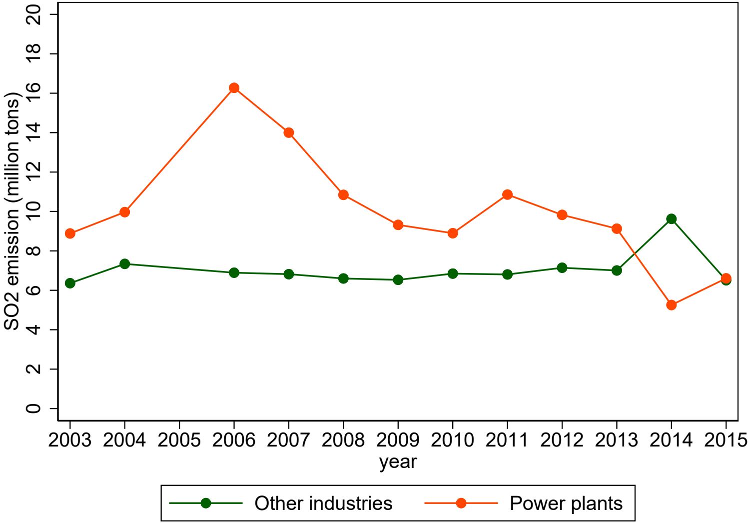
Pollution fees

- In 2003, most Chinese provinces started assessing fees of CNY 0.21 (approximately USD 0.03) per KG of SO_2 and NO_X discharged
  - Fees were doubled in 2004 and increased 50% more in 2005
  - Remained same across provinces (except Beijing)
- This changed with 11th Five-Year Plan, submitted by the State Council in 2006
  - Specified targeted pollution drops for these two pollutants by province
- Starting in 2007, many provinces raised fees above the national level
- We collected SO_2 fees by examining source documents from Chinese provinces
  - Created a province-year panel of fees
  - SO_2 and NO_X fees have 0.95 correlation, so we focus on SO_2 fees
- Interpretation of fees
  - High fees may proxy for more stringent environmental regulations

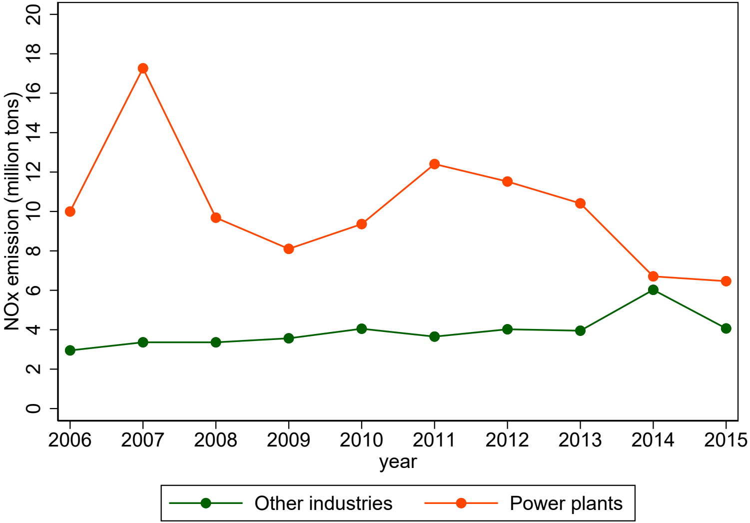
Focus on power plants

- The pollution fees included both charges for air pollution and water pollution
  - Water pollution measured with chemical oxygen demand (COD)
  - Water pollution fees were not as well assessed as air pollution fees
- For these reasons, we focus on air pollution fees and power plants

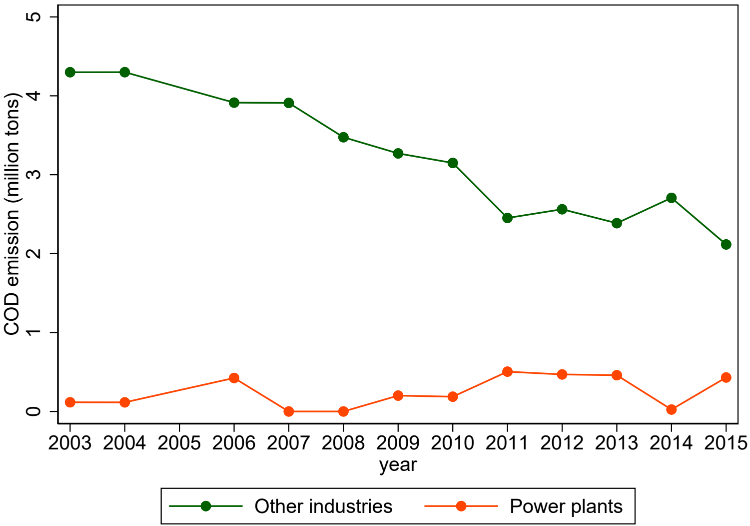
Total sulfur dioxide (SO_2) emissions by source



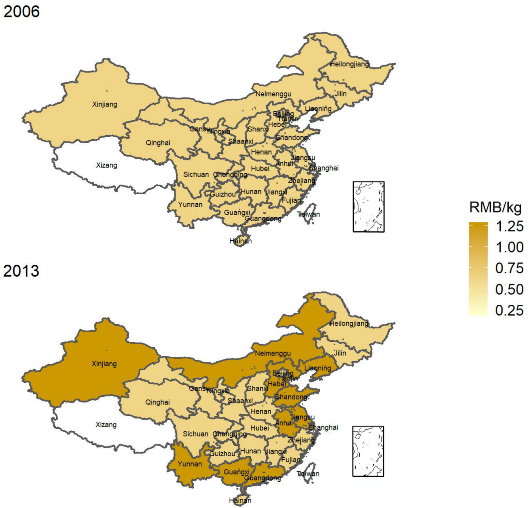
Total nitrogen oxide (NO_X) emissions by source



Chemical oxygen demand (COD) emissions by source



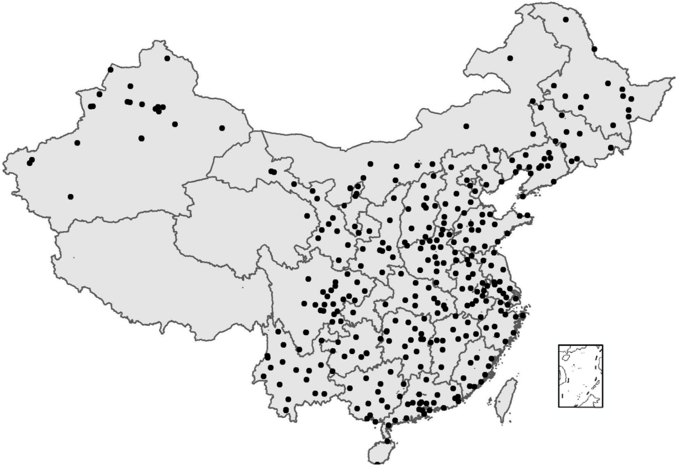
SO_2 fees by province in 2006 and 2013



Ambient pollution monitors

- We obtain data from Ebenstein et al. (2017)
- That study compiled pollution monitor data from multiple sources
- Our ambient pollution data extends from 2003 to 2012
  - Includes three pollutants: SO_2, NO_X, and PM10s
  - PM10s are particulate matters $\leq$ 10 micrometers in diameter
- Many monitors were not in operation for the whole sample period

Ambient pollution monitor map used in estimation



Summary statistics on ambient air pollution

Pollutant	Mean	Std. Dev.	N
Sulfur dioxide (SO_2) ($\mu g/m^3$):	42.167	25.068	1971
Nitrogen dioxide (NO_X) ($\mu g/m^3$):	30.525	12.060	1970
Particulate matter (PM10) ($\mu g/m^3$):	86.305	31.576	1961

Environmental discharge data

- We use the Chinese Environmental Survey (CES) data, 2004-15
    - Reports pollution discharges for power generation firms at the firm/year level
    - Derived from data collected by Chinese Ministry of Environmental Protection
    - Most comprehensive environmental dataset in China and only recently accessible to researchers
    - Supposed to record 85% of air pollution by sector
- The data report SO_2 and NO_X discharges
- An important issue is whether reporting is downwardly biased
    - Compared data to 2016 Chinese Statistical Yearbook on the Environment
    - Yearbook data are generally considered accurate
    - CES data reported 8.002—and Yearbook reports 8.711—million tons of SO_2
    - Thus, CES data capture 91% of total emissions in 2016, more than 85% goal

Summary statistics on environmental data for power plants

Variable	Value
Number of firm/year observations:	55,160
Number of unique firms:	12,504
Mean SO_2 emissions (tons):	2,223 (11,227)
Mean NO_X emissions (tons):	1,693 (26,793)
Mean coal consumption (tons):	1,160,636 (6.09e+07)
Mean oil consumption (tons):	914 (830,469)
Mean gas consumption (1000 cubic meters):	914 (90,811)

Note: standard deviations are included in parentheses.

Production data

- Production data is from Chinese Annual Survey of Industrial Production, 2004-13
  - We use data from power generation firms, based on the two-digit industrial sector code
- Data derive from annual surveys conducted by National Bureau of Statistics
  - They include non-state-owned firms with sales above CNY 5 million per year
  - They also include all state-owned firms
- We follow Brandt et al. (2012) in our variable choice and deflation measures
- We exclude 2010 and 2012 data due to known issues with the data (Brandt et al., 2017)

Summary statistics on production data for power plants

Variable	Value
Number of firm/year observations:	60,601
Number of unique firms:	10,914
Mean output (1000 CNY):	473,563 (3,901,136)
Mean labor (number of workers):	497 (2,186)
Mean capital (1000 CNY):	593,962 (3,830,152)

Note: standard deviations are included in parentheses.

Summary statistics on merged data

Variable	Value
Number of firm/year observations:	18,429
Number of unique firms:	3,573
Mean output (1000 CNY):	604,976 (4,112,323)
Mean labor (number of workers):	582 (1,818)
Mean capital (1000 CNY):	743,533 (2,937,394)
Mean SO_2 emissions (tons):	4,446 (11,227)
Mean NO_X emissions (tons):	2,857 (26,793)
Mean coal consumption (tons):	1,044,117 (3.79e+07)
Mean oil consumption (tons):	1186 (15,839)
Mean gas consumption (1000 cubic meters):	292 (4,810)

Note: standard deviations are included in parentheses.

Model

- Production model with firms $i = 1, \ldots, I$ and time periods (years) $t = 1, \ldots, T$:
  - In logs, firms produce output y_{it} and discharges d_{it} using inputs $k_{it}^1, \ldots, k_{it}^J$
  - Observed logged output is $y_{it}^* = y_{it} + \varepsilon_{it}$, where ε_{it} is measurement error
  - With a Cobb-Douglas specification:

$$y_{it} - \beta^d d_{it} = \beta^{k1} k_{it}^1 + \ldots + \beta^{kJ} k_{it}^J + \omega_{it} + \varepsilon_{it}$$

  - We expect that it is costly to discharge pollution: $\beta^d < 0$
- Paper estimates impact of pollution fees on pollution and productivity
  - Fees vary across Chinese provinces $p = 1, \ldots, P$ and time, f_{pt}
- TFP term ω_{it} may correlate with fees
  - Areas with productivity growth may have more pollution, leading to higher fees
  - We control for this with a series of fixed effects and interactions

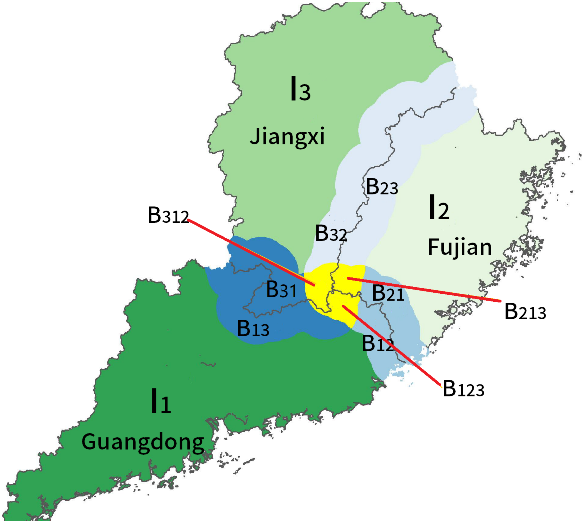
Estimation

- We estimate a series of specifications based on our model developed above
  - Dependent variables include ambient pollution, discharges d_{it}, and production y_{it}
  - Regressors are fees, production inputs, and fixed effects/interactions
- Units of observation:
  - Ambient pollution regressions are at the monitor/year level
  - Production and discharge regressions are at the firm/year level
  - Firms in Chinese data are more like plants in U.S. data
- A central complication is variation across China in TFP growth
  - Growth in coastal Chinese provinces increased before interior provinces
- Our research design controls for these factors with interactions
  - Include *local area* $\times$ year interactions
  - Also include firm fixed effects in many cases
- Two-way clustering at monitor/year, province/year, or region/year levels

Identification

- Our identification is from difference-in-difference for local border areas
  - We define a local border area as being within 50 KM of a provincial border
  - Local interior areas are those not within the 50 KM distance
- Identification assumption is that residual of ω_{it} is uncorrelated with f_{pt}
  - E.g., TFP increases symmetrically in Fujian-Guangdong border region
  - It didn't change more on one side than on the other, correlating with fee changes
- Identify effect of fees if there are relative changes in dependent variables in border
  - E.g., if pollution goes down on Guangdong side of border after fees raised
- Estimators with firm fixed effects further separate within versus between effects
  - We get to this more in our results on decomposition of productivity changes

Map of southeast China with regions to illustrate identification



Effect of pollution fees on ambient air pollution

	All sample	All sample	All sample	All sample	Borders only	Borders only
Panel A: ambient SO_2						
log(SO_2 fee)	0.129	0.163*	-0.134	-0.146	-0.134	-0.146
	(0.0837)	(0.0797)	(0.208)	(0.206)	(0.217)	(0.206)
Observations	1971	1962	1677	1669	375	374
Panel B: ambient NO_X						
log(NO_X fee)	0.384***	0.190**	-0.0827**	-0.101	-0.0827**	-0.101
	(0.0875)	(0.0815)	(0.0263)	(0.120)	(0.0338)	(0.121)
Observations	1862	1853	1589	1581	356	355
Panel C: ambient PM10						
log(SO_2 fee)	0.164***	0.136**	-0.0310**	-0.0257	-0.0310*	-0.0257
	(0.0442)	(0.0428)	(0.0126)	(0.0199)	(0.0149)	(0.0203)
Observations	1961	1952	1669	1661	375	374
Year FE	Yes	Yes				
Region×province FE	Yes		Yes		Yes	
Region×year FE			Yes	Yes	Yes	Yes
Monitor FE		Yes		Yes		Yes

Effect of pollution fees on power plant pollutant emissions

	All sample	All sample	All sample	All sample	Borders only	Borders only
Panel A: Dependent variable: $\log(SO_2 + 1)$ *emissions*						
log(SO_2 fee)	-0.0948	-0.345*	-0.328*	-0.445***	-0.328	-0.445*
	(0.178)	(0.160)	(0.154)	(0.132)	(0.211)	(0.219)
R^2	0.225	0.784	0.260	0.804	0.320	0.804
Observations	55,157	51,764	54,984	51,584	17,733	16,512
Panel B: Dependent variable: $\log(NO_X + 1)$ *emissions*						
log(NO_X fee)	-0.0785	-0.0980	-0.348**	-0.221**	-0.348	-0.221*
	(0.220)	(0.0546)	(0.118)	(0.0764)	(0.191)	(0.0993)
R^2	0.207	0.725	0.256	0.745	0.282	0.753
Observations	48,522	45,134	48,389	44,996	15,530	14,329
Year FE	Yes	Yes				
Region×province FE	Yes		Yes		Yes	
Region×year FE			Yes	Yes	Yes	Yes
Firm FE		Yes		Yes		Yes

Effect of pollution fees on power plant fuel consumption

	All sample	All sample	All sample	All sample	Borders only	Borders only
Panel A: Dependent variable: log(Coal+1)						
log(SO_2 fee)	-0.119**	-0.397***	-0.271	-0.383**	-0.271	-0.383*
	(0.0444)	(0.0517)	(0.198)	(0.162)	(0.191)	(0.196)
Observations	55,157	51,764	54,984	51,584	17,733	16,512
Panel B: Dependent variable: log(Oil+1)						
log(SO_2 fee)	0.0174	0.0451	0.223***	0.225***	0.223*	0.225
	(0.0674)	(0.0401)	(0.0548)	(0.0639)	(0.124)	(0.126)
Observations	50434	46993	50275	46827	16192	14966
Panel C: Dependent variable: log(Natural gas+1)						
log(SO_2 fee)	0.157	0.272*	0.0826	0.203	0.0826	0.203
	(0.144)	(0.127)	(0.184)	(0.208)	(0.242)	(0.231)
Observations	50,434	46,993	50,275	46,827	16,192	14,966
Year FE	Yes	Yes				
Region×province FE	Yes		Yes		Yes	
Region×year FE			Yes	Yes	Yes	Yes
Firm FE		Yes		Yes		Yes

Effect of fees on power plant output

	All sample	All sample	All sample	All sample	Borders only	Borders only
Panel A: Base results						
log(SO_2 fee)	-0.111	-0.0799	-0.0123	-0.217**	-0.0310	-0.223*
	(0.0840)	(0.0758)	(0.0908)	(0.0774)	(0.122)	(0.100)
Panel B: With fee interactions						
log(SO_2 fee)	-0.314	0.0956	-0.181	-0.0859	-0.164	0.163
	(0.203)	(0.194)	(0.158)	(0.188)	(0.582)	(0.259)
log(L)×log(SO_2 fee)	-0.0998**	-0.0849**	-0.118**	-0.107***	-0.0861*	-0.0994**
	(0.0381)	(0.0355)	(0.0392)	(0.0314)	(0.0435)	(0.0390)
log(K)×log(SO_2 fee)	0.0630*	0.0254	0.0701**	0.0403*	0.0518	0.0154
	(0.0280)	(0.0191)	(0.0269)	(0.0189)	(0.0540)	(0.0218)
log(L), log(K), log(Coal+1), log(Oil+1), and log(Gas+1) included as regressors						
Year FE	Yes	Yes				
Region×Province FE	Yes		Yes		Yes	
Region×Year FE			Yes	Yes	Yes	Yes
Firm FE		Yes		Yes		Yes

Decompositions of productivity changes

- To examine mechanisms, we decompose our findings on productivity into:
  1. Changes of productivity within a firm
  2. Reallocation of production across firms
  3. The cross term between these
  4. Entry by high productivity firms
  5. Exit of low productivity firms
- Use same regression as last specifications (firm FEs, border only) but without fees
  - As TFP, we decompose firm FE + residual (but not region $\times$ year interactions)
  - We weight measures by output
- We perform this decomposition separately by treatment and control provinces:
  - Allows us to understand mechanisms by which fees affect productivity
  - In time t, treatment province is one that raised fees at time $t-1$ or t
- We also do similar decompositions for pollution regressions

Results of base decomposition for productivity

Fraction TFP changed	Control	Treatment
Within	-2.24%	4.25%
Between	-.4.55%	2.20%
Cross	9.95%	2.05%
Entry	17.24%	-2.59%
Exit	-1.73%	1.19%
Total effect	22.13%	.32%

- The biggest difference between treatment and control provinces is in entry
- Control provinces (which didn't raise fees) had more entry of high productivity firms
- Cross effect for control provinces is also large
    - Firms that increased productivity there produced more

Results of decomposition by capital and labor for productivity

	Labor-intensive		Capital-intensive	
Fraction TFP changed	Control	Treatment	Control	Treatment
Within	-15.81%	-6.54%	-.61%	6.79%
Between	-11.83%	-8.78%	-5.05%	-1.89%
Cross	22.61%	6.55%	10.13%	2.33%
Entry	-2.76%	-.05%	18.64%	-1.16%
Exit	-1.88%	-3.76%	-.77%	2.65%
Total effect	-5.92%	-5.08%	23.88%	3.43%

- Capital- and labor-intensive firms have very different changes in productivity
- TFP goes up in control provinces due to two main reasons:
  1. The entry of capital-intensive firms
  2. Cross effects: labor-intensive firms that get more productive produce more

Results of base decomposition for pollution

Fraction SO_2 changed	Control	Treatment
Within	21.55%	-28.81%
Between	-8.47%	-11.26%
Cross	-6.09%	4.37%
Entry	-54.88%	-15.26%
Exit	-26.00%	-3.42%
Total effect	-21.85%	-47.55%

- In treatment provinces, pollution for existing firms went down a lot
  - Corresponding increase in control provinces suggests leakage effect
- Nonetheless, new entrants in control provinces had lower pollution
  - Consistent with greater number of entrants in control provinces

Conclusions

- First paper to study Chinese pollution discharge fees
  - These fees are similar in spirit to Pigouvian taxes
- We use a difference-in-difference in local border area identification approach
- Pollution fees appear to have:
  - Reduced pollution discharges from power plants
  - Caused them to use less coal
  - Lowered their productivity
  - Increased the relative productivity of capital-intensive power plants
  - And, some evidence that they reduced ambient pollution in treated areas
- Mechanisms for productivity changes
  - Entrants in treatment provinces had lower TFP
  - Particularly true for capital-intensive entrants
  - Labor-intensive firms shifted production to higher productivity firms