Manufacturing Pollution, Environmental Regulation and Trade

Dan Xie
School of Economics and Finance
Queen Mary University of London

EEA-ESEM
25 August, 2022

Introduction

China's trends 2000-2012:

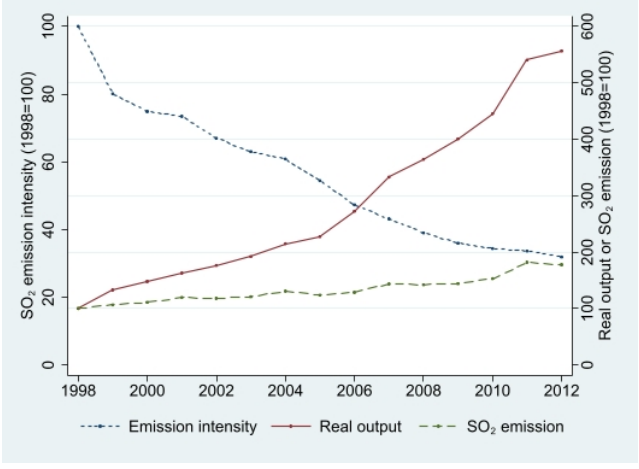

Figure 1. SO_2 emission and real output

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Research question:

- What are the main causes of pollution emissions in China?
  - Technology, industry structure, international trade, environmental regulation...
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- Decomposition exercises to find inter/intra industry causes of pollution emissions.
- A structural model to quantify contributions of different factors.

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Main results:

- Large trading firms pollute more but have lower pollution intensity.
- Within-industry firm heterogeneity explains most of the change in pollution emissions, while industry composition is less important.
- Counterfactual analysis:
  - Environmental regulation $\rightarrow$ 50% less emissions
  - Trade liberalization $\rightarrow$ 40% less emissions
  - Demand increase $\rightarrow$ 200% more emissions

literature

Data and background

Firm-level sources:

- Environmental Statistics Database from the Ministry of Environment Protection
  - 85% of total pollution emissions ($\mathbf{SO_2}$, NO_x, smoke dust, COD, NH_3-N, wastewater)
- Annual Survey of Industrial Enterprises from the National Bureau of Statistics
  - Production information on firms with annual sales above threshold
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- World Input-Output Dataset (WIOD): Country-industry production and trade data
- China Statistical Yearbooks: Industry and provincial output and emission

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Environmental regulation:

- China's 11th Five-Year-Plan (2006-2010)
  - The first time to set specific SO_2 reduction targets (10%)
  - Each province negotiated with the central government for their share of the burden
  - Linked explicitly to the promotion of local leaders
  - Most provinces achieved or even exceeded their targets

Initial firm-level regressions

$$PollutionOutcome_{it} = \alpha_1 Exporter_{it} + \alpha_2 Importer_{it} + \alpha_3 Sales_{it} + \mu_s + \mu_c + \mu_t + \epsilon_{it} \quad (1)$$

Table 1. All firms

	(1) SO_2	(2) SO_2	(3) SO_2int	(4) SO_2int
$Exporter$	0.158***	-0.217***	-0.598***	-0.217***
	(0.008)	(0.007)	(0.008)	(0.007)
$Importer$	0.304***	-0.278***	-0.831***	-0.278***
	(0.010)	(0.009)	(0.010)	(0.009)
$Sales$		0.498***		-0.502***
		(0.001)		(0.001)
Constant	9.551***	6.048***	2.506***	6.048***
	(0.002)	(0.008)	(0.002)	(0.008)
Obs.	798,666	777,539	777,539	777,539
R^2	0.194	0.376	0.414	0.545

Notes: SO_2 is SO_2 emission in kg. SO_2int is SO_2 emission/output value in thousand yuan. SO_2, SO_2int and $sales$ are in logs.
All columns include 4-digit CIC industry, county and year fixed effects.
Standard errors in parentheses. *** p <0.01, ** p <0.05, * p <0.1

statistics

Initial firm-level regressions

$$PollutionOutcome_{it} = \beta_1 Export_{it} + \beta_2 Import_{it} + \boldsymbol{\delta Control_{it}} + \mu_s + \mu_c + \mu_t + \epsilon_{it} \quad (2)$$

Table 2. Importing/Exporting firms

	(1) SO_2	(2) SO_2int	(3) SO_2int	(4) SO_2int	(5) SO_2int	(6) SO_2int	(7) SO_2int	(8) SO_2int
$Export$	0.130***	-0.042***	-0.041***	-0.020***	-0.018**	-0.021***	-0.021***	-0.018**
	(0.005)	(0.005)	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
$Import$	0.045***	-0.138***	-0.124***	-0.099***	-0.095***	-0.096***	-0.096***	-0.094***
	(0.004)	(0.004)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
$labor$			-0.003***	0.004***	0.003**	0.003**	0.003**	0.003**
			(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
TFP				-0.739***	-0.737***	-0.741***	-0.741***	-0.738***
				(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
foe					-0.401***	-0.402***	-0.402***	-0.402***
					(0.047)	(0.047)	(0.047)	(0.047)
$continue$						0.150***		
						(0.035)		
$entry$							-0.150***	
							(0.041)	
SO_2cap								0.015***
								(0.005)
Constant	6.702***	2.356***	2.416***	2.098***	2.060***	2.013***	2.163***	0.849*
	(0.072)	(0.080)	(0.100)	(0.109)	(0.109)	(0.110)	(0.112)	(0.447)
Observations	51,191	41,696	25,786	18,385	18,385	18,385	18,385	18,385
R^2	0.289	0.388	0.366	0.421	0.423	0.424	0.424	0.423

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statistics firm FE

Industry-level decomposition

Levinson (2009)

- Total pollution:

$$Z = \sum_s z_s = \sum_s x_s e_s = X \sum_s \kappa_s e_s \tag{3}$$

where total pollution is the sum of sector pollution z_s.
x_s is sector output, $e_s = z_s/x_s$ measures pollution intensity and $\kappa_s = x_s/X$ is sector share of total output.

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- In vector notation:

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- Totally differentiating:

$$dZ = \underbrace{\boldsymbol{\kappa}'\boldsymbol{e}dX}_{\text{scale}} + \underbrace{X\boldsymbol{e}'d\boldsymbol{\kappa}}_{\text{composition}} + \underbrace{X\boldsymbol{\kappa}'d\boldsymbol{e}}_{\text{technique}} \tag{5}$$

Industry-level decomposition

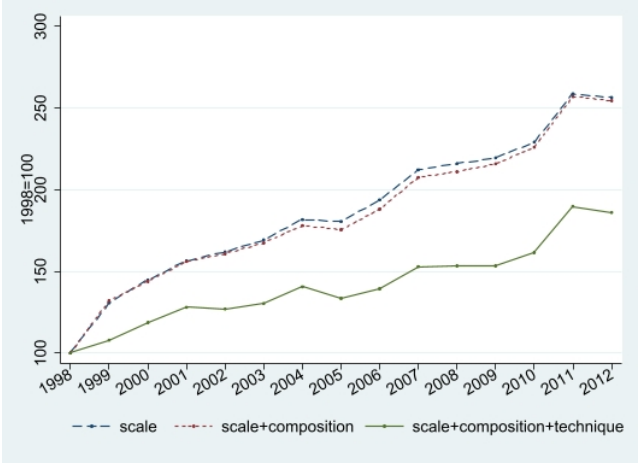

Figure 2. Industry-level SO_2 emission decomposition

firm-level

Model setup

How do trade, productivity and environmental regulation affect pollution?
What are the magnitudes of these effects?

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   - Monopolistic competition
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   - Firms pay pollution tax, wage cost and iceberg trade cost
   - Productivity is drawn from a Pareto distribution

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   - Productivity is drawn from a Pareto distribution
3. Production and pollution (follow Copeland and Taylor, 2003)
   - Firms pay a fraction a of cost on pollution abatement
   - α_s is the Cobb-Douglas share of pollution emissions

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Comparative statics

- Proposition: *Pollution intensity is decreasing in pollution tax, in productivity and in trade liberalization.*

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- Key variables (data): def
  - Implicit pollution tax ($\hat{t}_{o,s}$): Environmental regulation graph
  - Cobb-Douglas expenditure share ($\hat{\beta}_{d,s}$): Cobb-Douglas consumer preference graph
  - Market competitiveness of China and ROW ($\hat{\Gamma}_{od,s}$):
    Combines productivity, export trade costs and environmental regulation graph

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- Endogenous variables (model):
  - Firm mass ($\hat{M}^e_{o,s}$) and nominal wage ($\hat{w}_o$)
- Solve for $\hat{M}^e_{o,s}$ and $\hat{w}_o$ from a system of equations under equilibrium to get each sector's pollution emission between a baseline year and a counterfactual.
- Key parameters: Pollution elasticity α_s, elasticity of substitution σ_s, Pareto shape parameter θ_s. example

Counterfactual results

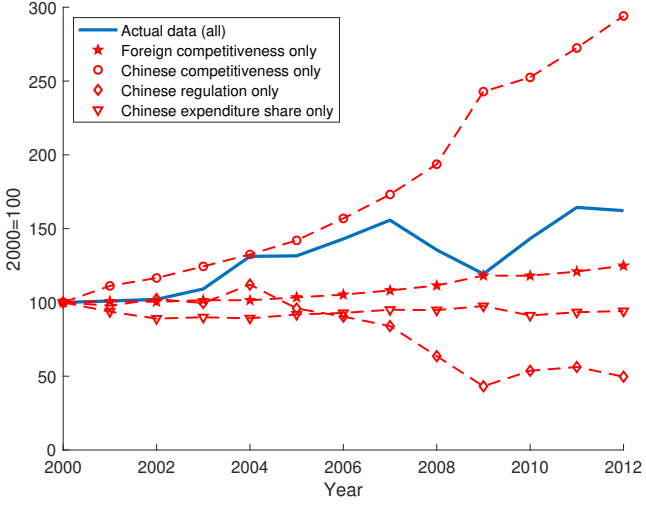

Figure 3. Counterfactual Chinese manufacturing SO_2 pollution emissions

Counterfactual results

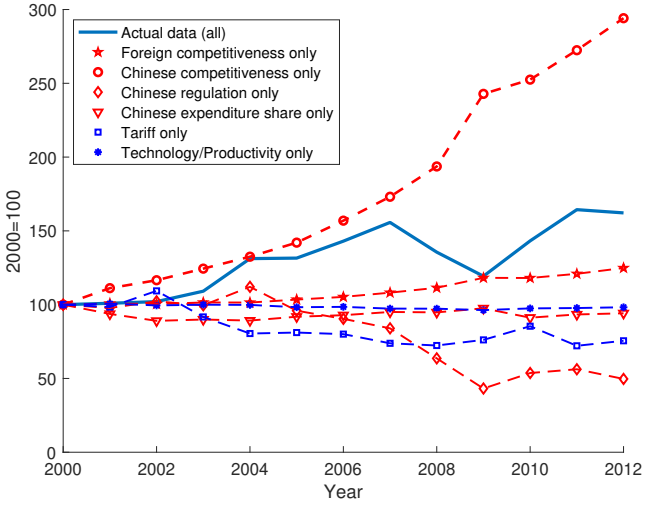

Figure 4. Additional counterfactuals (decomposed Chinese expenditure share)

historical values | intensity | sensitivity | other pollutants | policies

Thank you for your attention!

Literature

- Trade and technology:
  - NAFTA (Gutiérrez and Teshima, 2018)
  - China's entry into WTO (Forslid et al., 2018)
- Environmental regulation:
  - US Clean Air Act (1990) (Shapiro and Walker, 2018)
    Clean Water Act (1972) (Keiser and Shapiro, 2018)
  - China's 11th Five-Year-Plan (2006-2010) (Shi and Xu, 2018; Wu et al., 2017)
    and others (He et al., 2020; Tu et al., 2020)
- Decomposition:
  - Scale, composition and technique effects (e.g. Antweiler et al., 2001; **Levinson, 2009**)
  - Firm-level entry and exit (Melitz and Polanec, 2015)
- Quantitative model:
  - **Shapiro and Walker (2018)**, based on workhorse models from international (Melitz, 2003) and environmental (Copeland and Taylor, 2003) literatures
- Health effects and migration:
  - Bombardini and Li, 2020, Chang et al., 2019, Khanna et al., 2021, etc.

back

Data coverage

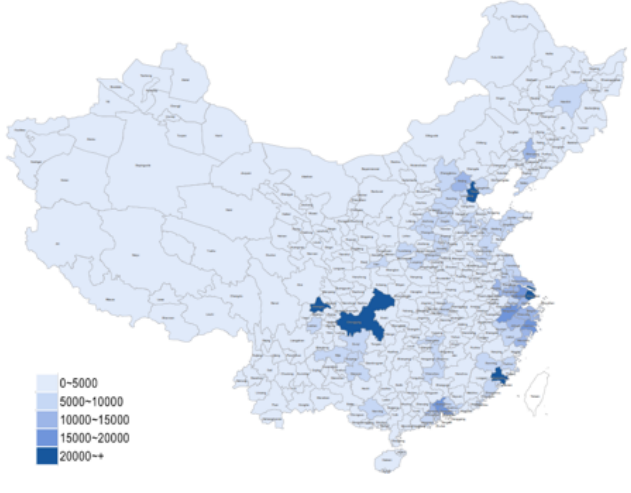

Figure 5. Number of firm-level observations: Pollution

Note: The total firm number between 2000 and 2012 is 245,479.

back

Data coverage

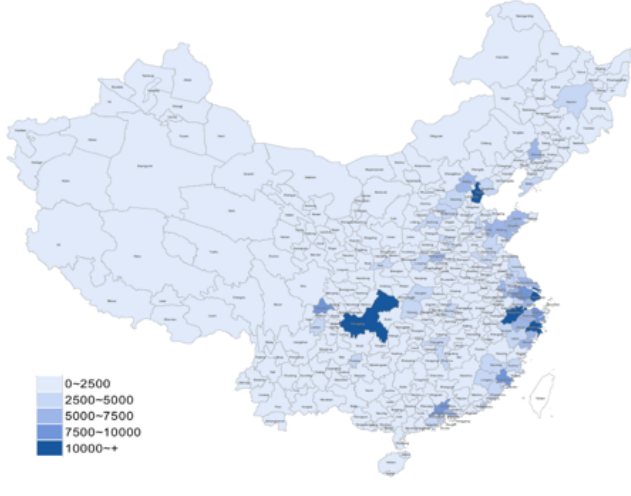

Figure 6. Number of firm-level observations: Pollution+ASIE

Note: The total firm number between 2000 and 2012 is 130,282.

back

Data coverage

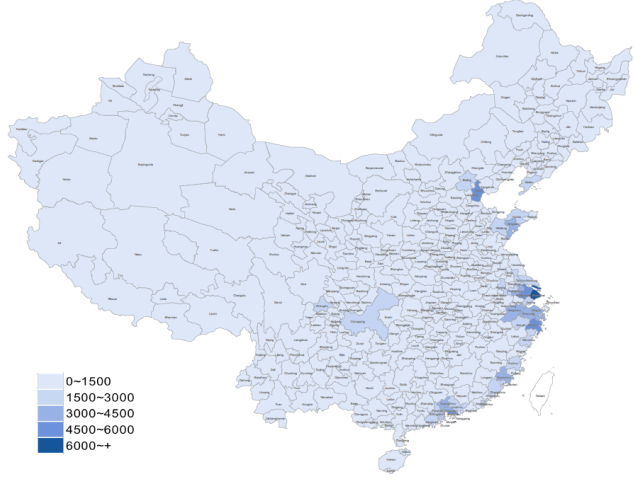

Figure 7. Number of firm-level observations: Pollution+ASIE+Customs

Note: The total firm number between 2000 and 2012 is 38,336.

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Summary statistics

Table 3. Summary statistics of all firms

Variable	Obs	Mean	Std. Dev.	Min	Max
$Exporter$	1,207,342	0.135	0.341	0	1
$Importer$	1,207,342	0.101	0.301	0	1
$Sales$	1,165,399	7.301	1.919	2.789	12.454
SO_2	877,406	9.580	1.899	3.738	14.353
SO_2int	854,355	2.360	2.223	-8.641	11.290

Notes: SO_2 is SO_2 emission (kg). SO_2int is SO_2 emission (kg) per unit of output value (1,000 RMB). SO_2, SO_2int and $Sales$ are in logs.

back

Summary statistics

Table 4. Summary statistics of importing/exporting firms

Variable	Obs	Mean	Std. Dev.	Min	Max
SO_2	116,747	9.421	2.224	2.485	15.011
SO_2int	85,124	0.356	2.340	-10.523	9.734
$Export$	168,672	14.545	2.223	7.746	19.612
$Import$	125,785	13.606	2.883	5.375	19.891
$labor$	84,449	8.762	22.830	0.310	80.190
TFP	64,049	0.252	0.960	-11.421	9.241
foe	142,316	0.163	0.369	0	1
$continue$	195,648	0.674	0.469	0	1
$entry$	195,648	0.180	0.384	0	1
$exit$	195,648	0.146	0.353	0	1
SO_2cap	178,747	83.377	44.386	0.200	160.200

Notes: SO_2 is SO_2 emission (kg). SO_2int is SO_2 emission (kg) per unit of output value (1,000 RMB). SO_2, SO_2int, $Export$ and $Import$ are in logs.

back

Initial firm-level regressions

Table 5. All firms

	(1) SO_2	(2) SO_2	(3) SO_2int	(4) SO_2int
$Exporter$	0.016**	-0.018***	-0.092***	-0.018***
	(0.007)	(0.007)	(0.007)	(0.007)
$Importer$	0.049***	0.018**	-0.042***	0.018**
	(0.007)	(0.007)	(0.008)	(0.007)
$Sales$		0.323***		-0.677***
		(0.002)		(0.002)
Constant	9.610***	7.273***	2.361***	7.273***
	(0.001)	(0.012)	(0.001)	(0.012)
Observations	829,220	806,958	806,958	806,958
R^2	0.810	0.820	0.838	0.872

Notes: SO_2 is SO_2 emission in kg. SO_2int is SO_2 emission/output value in thousand yuan. SO_2, SO_2int and $sales$ are in logs.
All columns include firm and year fixed effects.
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back

Initial firm-level regressions

Table 6. Importing/Exporting firms

	(1) SO_2	(2) SO_2	(3) SO_2int	(4) SO_2int	(5) SO_2int	(6) SO_2int
$Export$	0.045***	0.036***	-0.054***	-0.055***	-0.045***	-0.045***
	(0.005)	(0.008)	(0.007)	(0.010)	(0.011)	(0.011)
$Import$	0.011***	0.004	-0.033***	-0.036***	-0.050***	-0.050***
	(0.004)	(0.006)	(0.005)	(0.007)	(0.008)	(0.008)
$labor$		0.010***		-0.003	-0.006**	-0.006**
		(0.002)		(0.002)	(0.003)	(0.003)
TFP					-0.732***	-0.732***
					(0.018)	(0.018)
SO_2cap						-0.007
						(0.011)
Constant	8.433***	8.828***	1.153***	1.472***	1.981***	2.521***
	(0.089)	(0.134)	(0.118)	(0.153)	(0.174)	(0.925)
Observations	50,836	22,357	37,066	21,768	14,531	14,531
R^2	0.856	0.846	0.834	0.825	0.841	0.841

Notes: SO_2 is SO_2 emission in kg. SO_2int is SO_2 emission/output value in thousand yuan.
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Firm-level decomposition

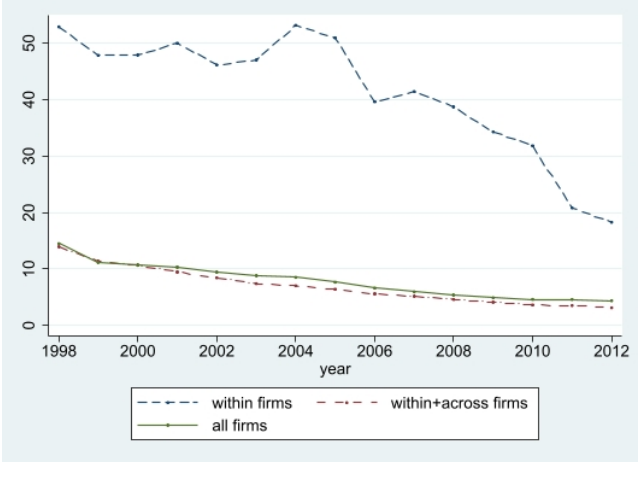

Figure 8. Firm-level SO_2 emission intensity decomposition

details
back

Firm-level decomposition

Melitz and Polanec (2015)

- Change in pollution intensity:

$$\Delta\iota = \underbrace{\underbrace{\Delta\bar{\iota}_C}_{\text{within-firm}} + \underbrace{\Delta\text{cov}_C}_{\text{across-firm}}}_{\text{continuing firms}} + \underbrace{s_{E2}(\iota_{E2} - \iota_{C2})}_{\text{entering firms}} + \underbrace{s_{X1}(\iota_{C1} - \iota_{X1})}_{\text{exiting firms}} \tag{6}$$

where $s_{Gt} = \sum_{i \in G} s_{it}$ is the aggregate revenue share of a group G of firms,
ι_{Gt} is the group's aggregate (average) emission intensity,
$\bar{\iota}_C$ is the unweighted mean firm emission intensity,
cov_C is the covariance between revenue share and emission intensity.

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Key variables for counterfactuals

1. Implicit pollution tax
   - Environmental regulation

$$\hat{t}_{o,s} = \frac{\hat{M}^e_{o,s}\hat{w}_o}{\hat{Z}_{o,s}} \tag{7}$$

where firm mass $\hat{M}^e_{o,s}$ and nominal wage $\hat{w}_o$ are endogenous variables of the model

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2. Expenditure share
   - Cobb-Douglas preference

$$\hat{\beta}_{d,s} = \frac{\sum_o X'_{od,s} / \sum_{o,s} X'_{od,s}}{\sum_o X_{od,s} / \sum_{o,s} X_{od,s}} \tag{8}$$

   $X_{od,s}$: total national value of exports from $o \to d$

back

Key variables for counterfactuals

3. Market competitiveness
   - Combines productivity ($\hat{b}_{o,s}$), exporting trade costs ($\hat{\tau}_{od,s}$, $\hat{f}_{od,s}$) and environmental regulation ($\hat{t}_{o,s}$)

$$\hat{\Gamma}_{od,s} = (1/\hat{b}_{o,s})^{-\theta_s}(\hat{\tau}_{od,s})^{-\theta_s/(1-\alpha_s)}(\hat{f}_{od,s})^{1-\theta_s/(\sigma_s-1)(1-\alpha_s)}(\hat{t}_{o,s})^{-\alpha_s\theta_s/(1-\alpha_s)} \tag{9}$$

$$= \frac{\hat{\lambda}_{od,s}}{\hat{M}^e_{o,s}\hat{w}_o^{-\theta_s}},\ o \neq \text{China} \tag{10}$$

$$\hat{\Gamma}_{od,s} = (1/\hat{b}_{o,s})^{-\theta_s}(\hat{\tau}_{od,s})^{-\theta_s/(1-\alpha_s)}(\hat{f}_{od,s})^{1-\theta_s/(\sigma_s-1)(1-\alpha_s)} \tag{11}$$

$$= \hat{t}_{o,s}^{\frac{\alpha_s\theta_s}{1-\alpha_s}} \frac{\hat{\lambda}_{od,s}}{\hat{M}^e_{o,s}\hat{w}_o^{-\theta_s}},\ o = \text{China} \tag{12}$$

$\hat{\lambda}_{od,s}$: share of country d's expenditure in sector s going to country o

back

Parameter estimates

1. Pollution elasticity α_s

$$q_{od,s} = (z_{od,s})^{\alpha_s}(\varphi l_{od,s})^{1-\alpha_s}$$

- Estimate:

$$\ln q_{it} = \alpha \ln z_{it} + (1-\alpha)\ln(\varphi l_{it}) + \eta_t + \eta_c + \eta_s + \epsilon_{it} \quad (13)$$

α: the average 2-digit sector pollution elasticity
z_{it}, q_{it} and l_{it}: pollution emission, output and labor employment of firm i
η_t, η_c and η_s: year, county and 4-digit CIC industry fixed effects

Parameter estimates

1. Pollution elasticity α_s

$$q_{od,s} = (z_{od,s})^{\alpha_s}(\varphi l_{od,s})^{1-\alpha_s}$$

   - Estimate:

$$\ln q_{it} = \alpha \ln z_{it} + (1-\alpha)\ln(\varphi l_{it}) + \eta_t + \eta_c + \eta_s + \epsilon_{it} \quad (13)$$

     α: the average 2-digit sector pollution elasticity
     z_{it}, q_{it} and l_{it}: pollution emission, output and labor employment of firm i
     η_t, η_c and η_s: year, county and 4-digit CIC industry fixed effects

2. Elasticity of substitution σ_s
   - Implication of the model:

$$w_o L^p_{o,s} = (1-\alpha_s)\frac{\sigma_s - 1}{\sigma_s} R_{o,s} \quad (14)$$

back

Parameter estimates

3. Pareto shape parameter θ_s
   - The distribution of firm sales is Pareto:

$$\Pr(x > X_{i,s}) = (b_{i,s}/X_{i,s})^{\theta_s/(\sigma_s - 1)} \quad \text{for} \quad X_{i,s} \geq b_{i,s} \tag{15}$$

Parameter estimates

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   - Taking logs gives:

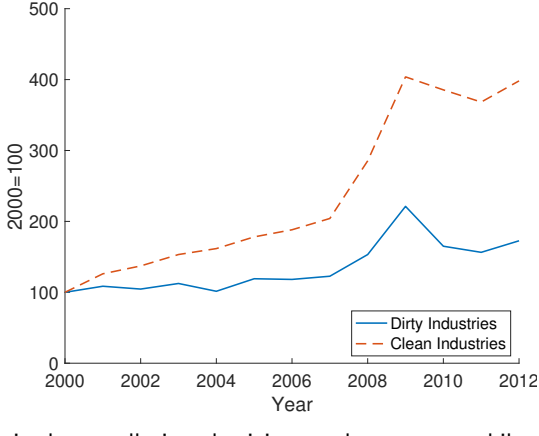
$$\ln(Pr\{x > X_{i,s}\}) = \gamma_{0,s} + \gamma_{1,s}\ln(X_{i,s}) + \epsilon_{i,s} \tag{16}$$

     where $X_{i,s}$ represents sales
   - The Pareto shape parameter $\theta_s = \gamma_{1,s}(1 - \sigma_s)$

back

Historical values of key variables (data)

Figure 9. Implicit pollution tax $\hat{t}_{o,s}$



Notes: Dirty industries have pollution elasticity α_s above mean, while clean industries are below average, weighted by baseline output of each industry.

- The State Council: SO_2 pollution charges doubled within three years since 2007, from 0.63 yuan per kilogram to 1.26 yuan per kilogram.

more details province back

Historical values of key variables (data)

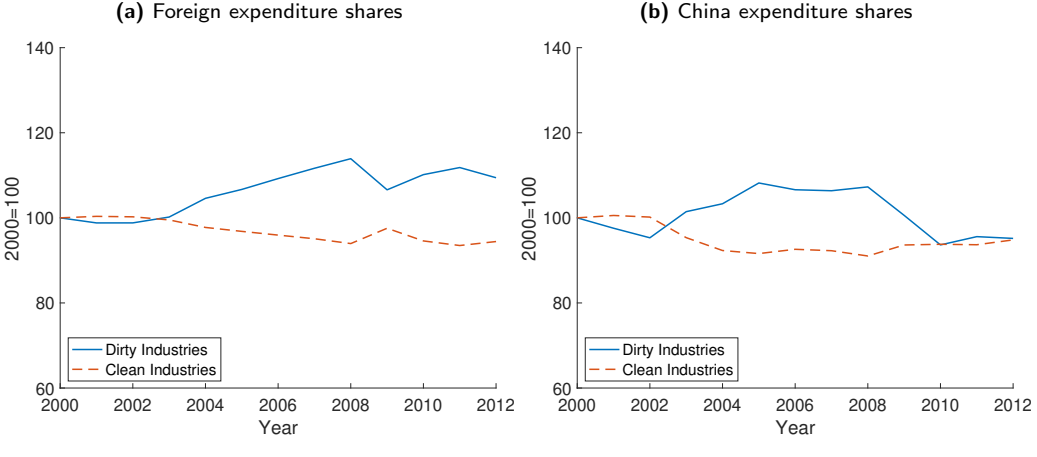


Figure 10. Expenditure shares $\hat{\beta}_{d,s}$

back

Historical values of key variables (model-implied)

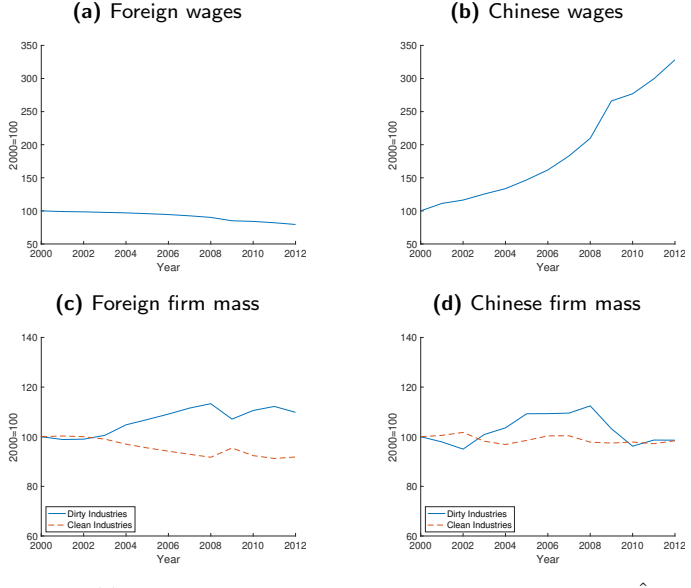


Figure 11. Historic values of endogenous variables $\hat{w}_o$ and $\hat{M}^e_{o,s}$

wage compare back

Historical values of key variables (data)

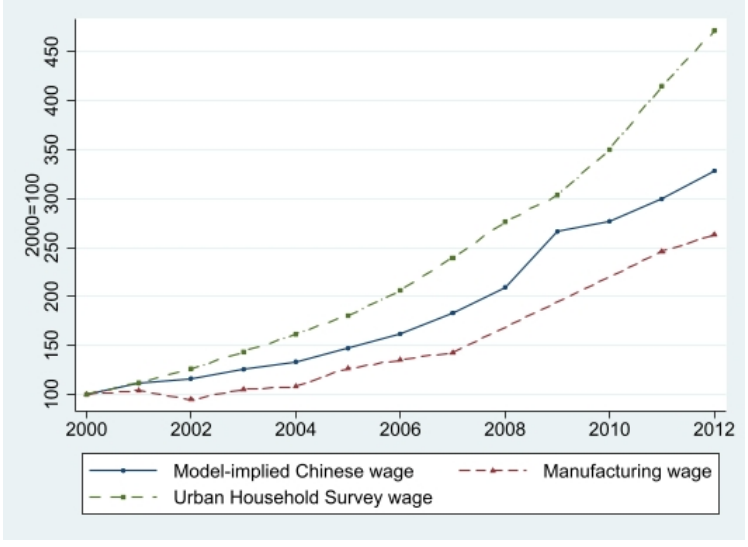


Figure 12. Chinese wages

back

Historical values of additional counterfactuals

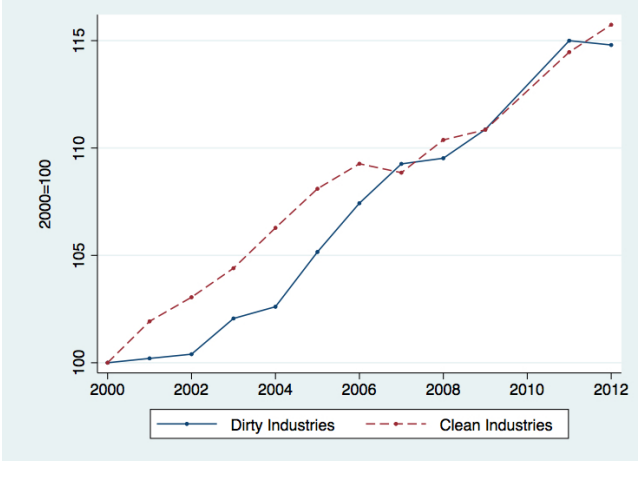


Figure 13. Log sector productivity

Notes: Dirty industries have pollution elasticity α_s above average, while clean industries are below average, unweighted mean.

back

Historical values of additional counterfactuals

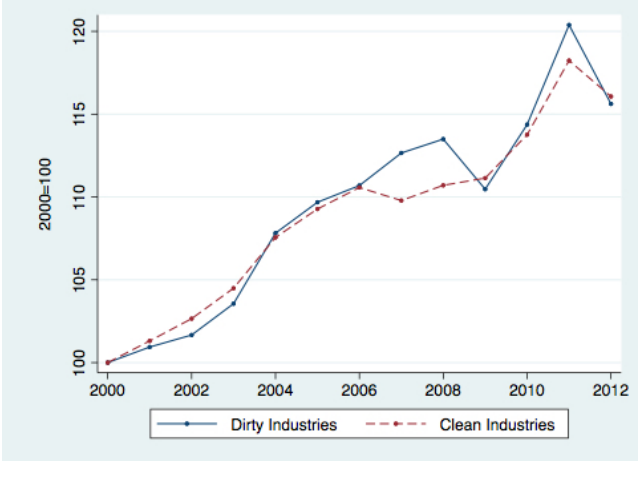


Figure 14. Log firm productivity

Notes: Dirty industries have pollution elasticity α_s above average, while clean industries are below average, unweighted mean.

back

Historical values of additional counterfactuals

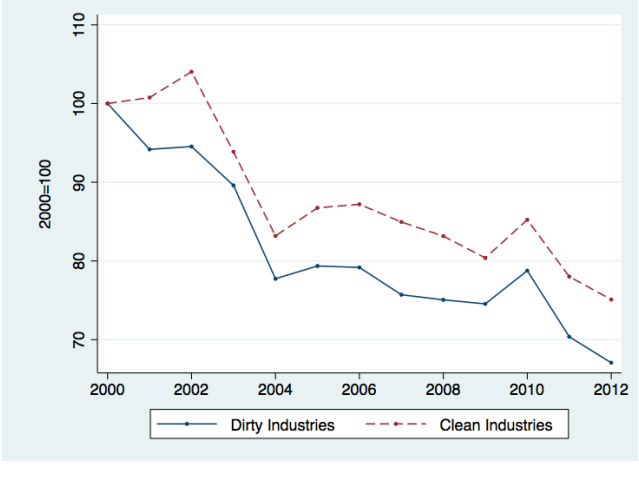


Figure 15. Export tariff

Notes: Dirty industries have pollution elasticity α_s above average, while clean industries are below average, unweighted mean.

back

Pollution intensity

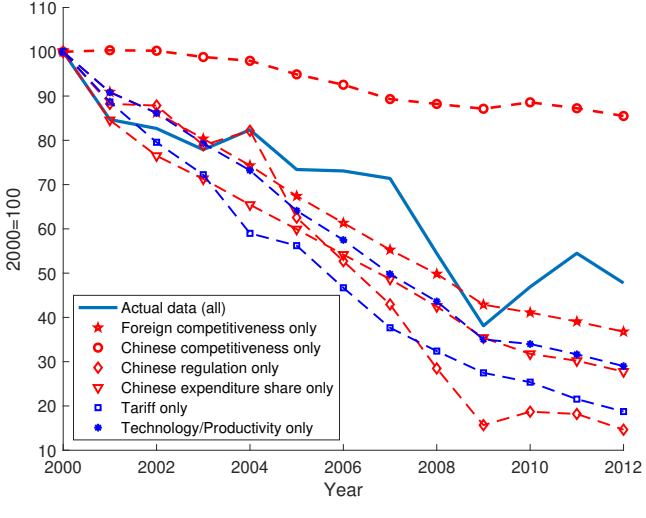


Figure 16. Counterfactual Chinese manufacturing pollution intensities

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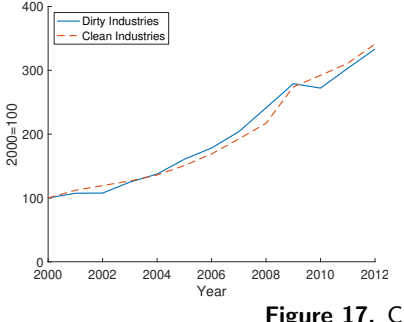
Changes in output and pollution

Changes in pollution tax $\hat{t}_{o,s}$ can be written as:

$$\hat{t}_{o,s} = \frac{\hat{R}_{o,s}}{\hat{Z}_{o,s}}$$

(a) Changes in sectoral output $\hat{R}_{o,s}$



(b) Changes in sectoral pollution $\hat{Z}_{o,s}$

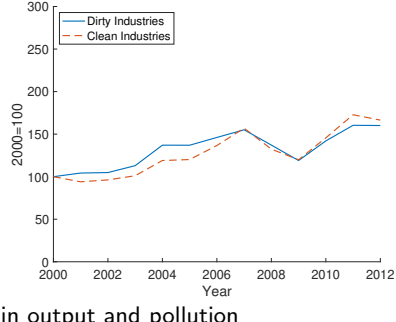


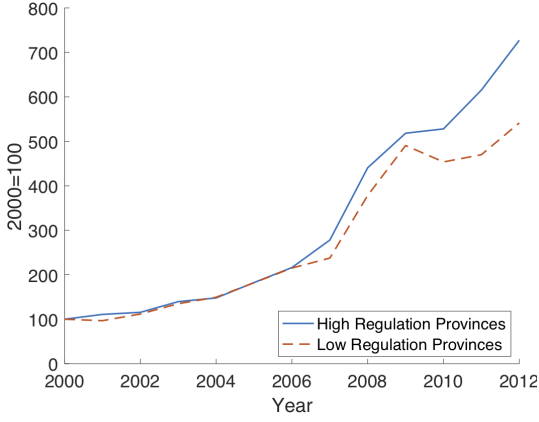
Figure 17. Changes in output and pollution

Note: $\hat{Z}_{o,s}$ drops relatively more than $\hat{R}_{o,s}$ around 2009

back

Historical values of key variables (data)

Figure 18. Implicit pollution tax $\hat{t}_{o,s}$ by province



Notes: High regulation provinces have above average SO_2 reduction over initial GDP ratio, while low regulation provinces are below average, weighted by baseline output of each province.

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Parameter estimates

Table 7. Parameter estimates (example)

CIC code 13-43	(1) Pollution elasticity (α)	(2) Elasticity of substitution (σ)	(3) Pareto shape parameter (θ)
16 Manufacture of Tobacco	0.0038	1.81	1.41
25 Processing of Petroleum, Coking and Nuclear Fuel	0.0789	22.58	17.00
Sector mean	0.0190	6.41	7.85
Standard deviation	0.0195	3.38	3.79

details back

Sensitivity analysis

Table 8. Sensitivity analysis

	Foreign competitiveness	Chinese competitiveness	Chinese expenditure shares	Chinese environmental regulation	Tariff	Technology/ productivity
1. Actual change			162.180			
2. Main estimate	124.857	294.114	94.152	49.663	63.566	98.361
3. σ: Feenstra	124.289	292.573	94.124	49.768	73.522	96.444
4. θ: top 25 %	124.400	289.512	94.136	49.800	71.307	95.794
5. θ: top 50 %	124.250	289.732	94.120	49.916	72.071	93.669
6. α: $\times$ 0.5	124.443	285.016	94.139	50.323	71.442	97.976
7. α: $\times$ 2	125.592	343.825	94.181	44.728	75.549	99.519
8. Partial equilibrium	100.000	100.000	100.000	50.815	100.000	100.000

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Counterfactuals of other pollutants

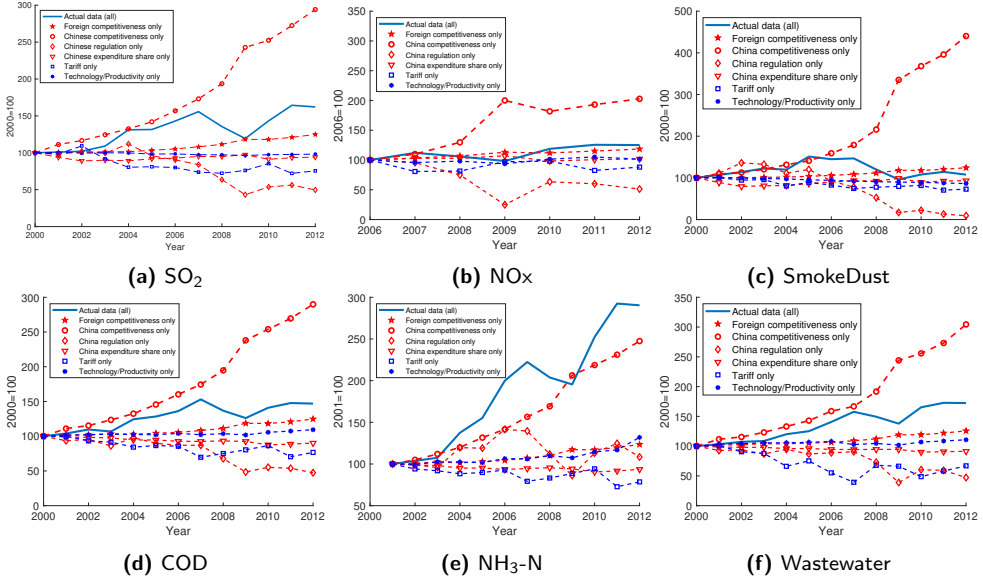

Figure 19. Counterfactuals of other pollutants

back

Counterfactual policies

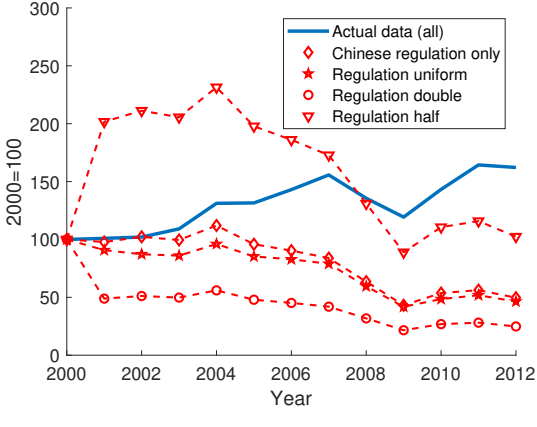

Figure 20. Counterfactual SO_2 emissions of alternative pollution policies

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Counterfactual policies

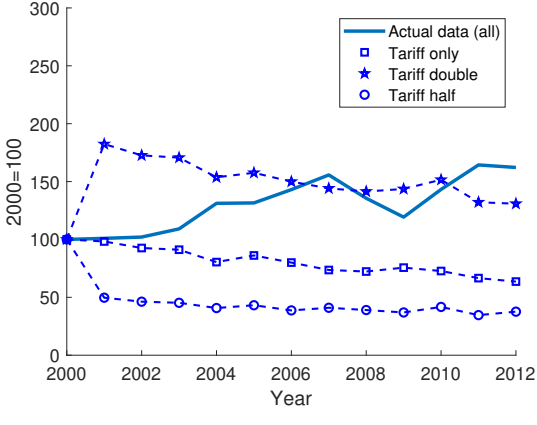

Figure 21. Counterfactual SO_2 emissions of alternative tariffs

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