Environmental Regulation and Firm-Level Productivity: Estimates from a Regression Discontinuity Design

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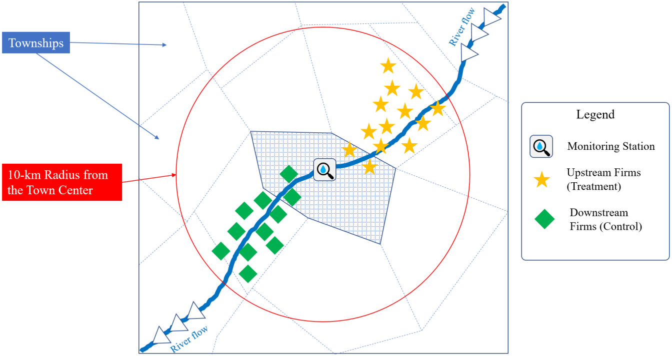
Motivation

- How does environmental regulation affect productivity?
  - Classical economic theory: regulation imposes extra cost on firms, thus reducing productivity.
  - The Porter Hypothesis: regulation causes technological upgrades, thus increasing productivity (Porter, 1991; Porter and van der Linde, 1995.).
- Existing empirical evidence mainly focuses on developed countries (Jaffe et al. 1995; Henderson 1996; Becker and Henderson 2000; Berman and Bui, 2001; Greenstone, 2002; Kahn and Mansur, 2010; Walker, 2011; Greenstone, List, and Syverson, 2012; Ryan, 2012; Walker, 2013.).
  - Despite having tremendous policy relevance for developing countries such as China and India, we have relatively little solid causal evidence in these settings.
  - Identification typically relies on using county-level emission reduction targets as proxies for regulation intensity, which could themselves be endogenously chosen.

This Paper

- We focus on China's surface water quality monitoring system, which creates spatially discontinuous incentives for local governments to regulate polluting firms around a monitoring station.



▸ Anecdotal Support for Research Design

This Paper

- Combining firm-level production and emission datasets, and exploiting this spatial discontinuity in regulation stringency, we estimate the effect of regulation on the productivity of polluting firms in China. We find that:
  - In polluting industries, upstream firms have a **27% lower TFP**, and a **48% lower emission level**, as compared to adjacent downstream firms.
  - In non-polluting industries, there does not exist such discontinuity between upstream and downstream firms.
  - Back of the envelope calculation suggests a >200 **billion Yuan annual GDP loss** due to China's water quality regulation program.

▸ Water Quality Monitoring Stations in China

Data

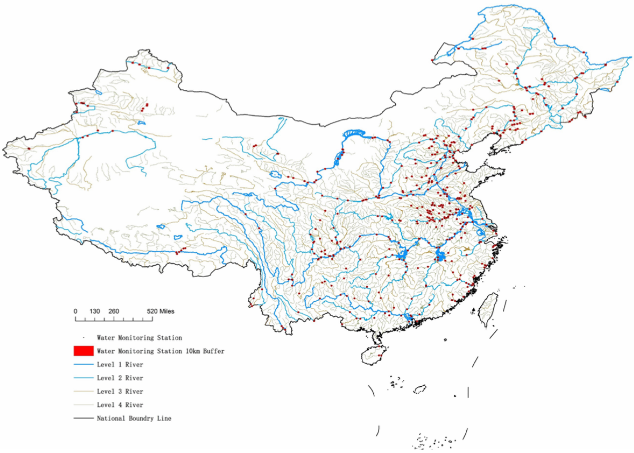
- Water quality monitoring stations collected from the China Environmental Yearbooks, China Environmental Statistical Yearbooks, and China Environmental Quality Statistical Yearbooks.
  - Covering all the national stations, geocoded, and cross-validated.
- Firm production data from the Annual Survey of Industrial Firms (ASIF) maintained by the National Bureau of Statistics (2000-2007).
  - Including all 952,376 industrial firms with annual sales above 5 million Yuan, we geocoded all of them.
  - Construct TFP following Olley and Pakes (1992).
- Firm emission data from the Environmental Statistics Database (ESD) maintained by the Ministry of Environmental Protection (2000-2007).
  - Covering major polluting firms in every county, altogether accounting for more than 85% of total emissions, we geocoded all of them.
- Other datasets: township data from the NBS, township GIS maps from the Michigan China Data Center, River GIS data from the MEP.

Data Matching

- Water quality monitoring stations are matched with China's water basin system, identify in which township a monitoring station is located
- A circle with a radius of 10 km from the town center is drawn, identify sampled townships
- Overlay ASIF and ESD firms on the map of identified townships
- Use elevation data to identify upstream/downstream information.

Map of Monitoring Stations and Townships

- 18,966 ASIF firms
- 14,144 ESD firms
- 161 water quality monitoring stations

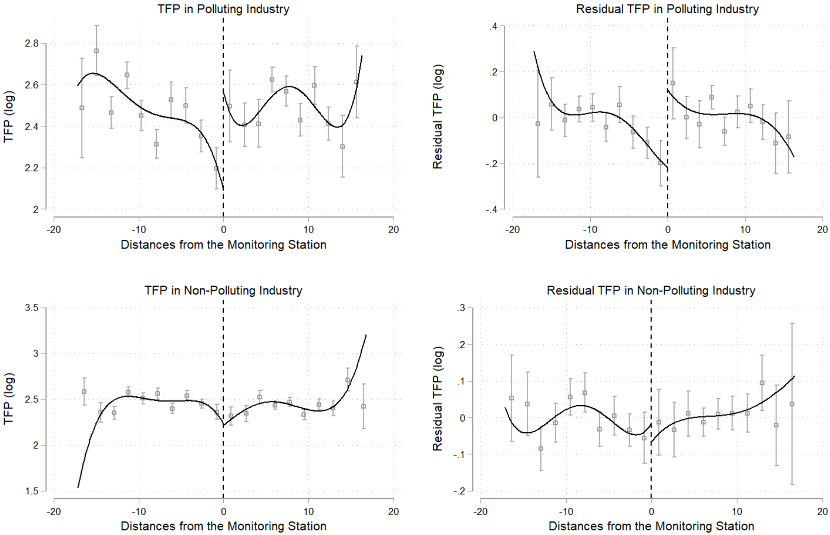


Econometric Model: Non-parametric RD

$$TFP_{ij} = \alpha_1 Down_{ij} + \alpha_2 Dist_{ij} + \alpha_3 Down_{ij} Dist_{ij} + u_j + \varepsilon_{ij}$$

- $s.t. -h \leq Dist_{ij} \leq h$
- h, length of bandwidth (i.e., the acceptable distance from the discontinuity for sample inclusion)
- A MSE-optimal bandwidth h is adopted
  - Calonico, Cattaneo, and Titiunik (2014) and Calonico, Cattaneo, Farrell (forthcoming)
- Tested with different kernel weighting functions

RD Plot: Effects of Water Quality Monitoring on TFP



RD Estimates: Water Quality Monitoring on TFP

Table 2. RD Estimates of the Impact of Water Quality Monitoring on TFP

	Polluting Industries			Non-Polluting Industries		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Water Quality Monitoring and TFP						
TFP (log) - Polluting Industries	0.36	0.38	0.43	-0.00	0.02	-0.05
	(0.23)	(0.24)	(0.28)	(0.14)	(0.15)	(0.14)
Bandwidth (km)	4.18	3.88	2.88	4.71	4.14	4.19
Panel B: Water Quality Monitoring and Residual TFP						
TFP (log) - Polluting Industries	0.25*	0.25**	0.33**	-0.01	0.00	0.02
(Station FE Absorbed)	(0.14)	(0.13)	(0.15)	(0.09)	(0.10)	(0.11)
Bandwidth (km)	5.80	5.98	4.82	6.02	5.48	4.26
Panel C: Water Quality Monitoring and Residual TFP						
TFP (log) - Polluting Industries	0.31**	0.31**	0.35**	0.02	0.03	0.03
(Station and Industry FE Absorbed)	(0.15)	(0.15)	(0.16)	(0.08)	(0.08)	(0.09)
Bandwidth (km)	6.56	6.54	5.41	5.553	4.918	4.329
Obs.	6,582	6,582	6,582	12,422	12,422	12,422
Kernel	Triangle	Epanech.	Uniform	Triangle	Epanech.	Uniform

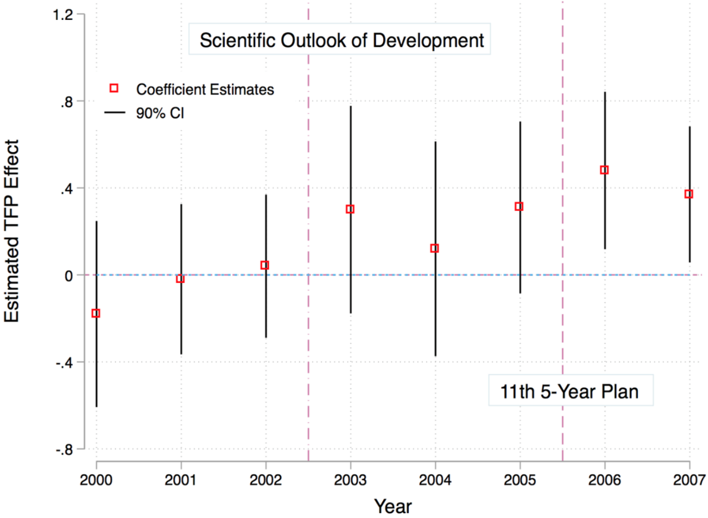
Regulations reduce upstream polluting firms' TFP by roughly 27%.

Heterogeneity

Table 3. Heterogeneous Impacts of the Impact of Water Quality Monitoring on TFP

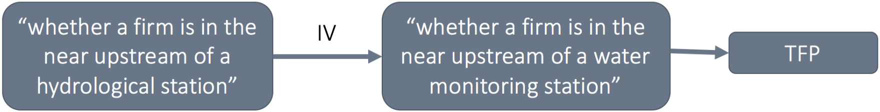
	Residual TFP – Polluting Industries			Residual TFP – Non-Polluting Industries		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: By Ownership						
Private Firms	0.34**	0.37**	0.31*	0.04	0.04	0.03
	(0.17)	(0.18)	(0.18)	(0.08)	(0.08)	(0.09)
Obs.	5,636	5,636	5,636	10,084	10,084	10,084
Bandwidth	5.965	5.590	5.087	6.052	6.059	5.537
SOEs	-0.31	-0.16	0.23	-0.13	-0.10	-0.01
	(0.52)	(0.54)	(0.50)	(0.25)	(0.25)	(0.27)
Obs.	635	635	635	1,357	1,357	1,357
Bandwidth	4.282	4.474	4.407	4.724	4.545	3.955
Foreign Firms	-0.06	-0.07	-0.11	-0.12	-0.15	0.02
	(0.27)	(0.28)	(0.31)	(0.40)	(0.42)	(0.25)
Obs.	1,104	1,104	1,104	2,427	2,427	2,427
Bandwidth	6.927	6.541	5.479	3.287	3.070	4.286
Panel B: By Year						
Before 2003	0.09	0.10	0.11	0.01	0.01	0.06
	(0.19)	(0.20)	(0.24)	(0.12)	(0.13)	(0.15)
Obs.	2,570	2,570	2,570	4,565	4,565	4,565
Bandwidth	5.722	5.211	3.359	4.375	4.323	3.533
After 2003	0.36**	0.35**	0.40**	0.03	0.04	0.07
	(0.16)	(0.16)	(0.17)	(0.08)	(0.09)	(0.10)
Obs.	5,916	5,916	5,916	10,992	10,992	10,992
Bandwidth	6.223	6.287	5.159	6.302	5.926	5.050
Panel C: By Firm Age						
Old Firms	0.40**	0.45**	0.47**	0.00	0.01	0.04
	(0.19)	(0.20)	(0.21)	(0.09)	(0.10)	(0.11)
Obs.	4,332	4,332	4,332	7,866	7,866	7,866
Bandwidth	6.118	5.645	4.697	5.341	5.229	4.418
Young Firms	-0.55	-0.29	0.30	0.25	0.23	0.09
	(0.86)	(0.68)	(0.49)	(0.25)	(0.26)	(0.30)
Obs.	953	953	953	1,769	1,769	1,769
Bandwidth	3.282	3.769	4.596	4.368	4.083	3.250
Kernel	Triangle	Epanech.	Uniform	Triangle	Epanech.	Uniform

TFP Effects by Year



Using Hydrological Stations as an IV

- Local governments locate water monitoring stations close to existing hydrological stations to share facilities and data.
- Hydrological stations were built between 1950s and 1970s, and the locations were chosen purely based on hydrological considerations.
- Having a hydrological station in the near downstream should only matter for a polluting firm if it brings a monitoring station close to it.
- Otherwise, downstream hydrological stations will have no direct influence on the polluting firm's productivity



IV Estimation using Hydrological Stations

Table 4. Instrumental Variable Estimation using Hydrological Stations

	Polluting Industries		Non–Polluting Industries	
	Upstream	TFP (log)	Upstream	TFP (log)
	(1)	(2)	(3)	(4)
Upstream Hydrological Station	0.38**		0.31**	
	(0.18)		(0.14)	
Upstream Monitoring Station		-0.35**		-0.00
		(0.16)		(0.17)
Specification	1st Stage	2SLS	1st Stage	2SLS
Station FE	Y	Y	Y	Y
Observations	4,445	4,462	8,976	8,981
F Statistic	10.48	0.03	22.82	1.18
R-squared	0.47	0.16	0.44	0.09

Political Economy of Water Regulation

Table 9. Political Economy of Water Quality Monitoring

	Conventional Local RD		Bias-Corrected RD		Bias-Corrected Robust	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. When City Leader Has Strong Political Incentives						
TFP (log)	0.57***	0.59***	0.63***	0.66***	0.63***	0.66***
	(0.19)	(0.20)	(0.19)	(0.20)	(0.21)	(0.23)
Panel B. When City Leader Has Weak Political Incentives						
TFP (log) - Polluting Industries	0.01	0.08	0.00	0.07	0.00	0.07
	(0.23)	(0.24)	(0.23)	(0.24)	(0.29)	(0.31)
Panel C. Automatic Monitoring Stations						
TFP (log)	0.92	1.01*	1.11*	1.22**	1.11	1.22*
	(0.59)	(0.57)	(0.59)	(0.57)	(0.74)	(0.71)
Panel D. Manual Monitoring Stations						
TFP (log)	0.26*	0.26*	0.27*	0.27*	0.27	0.27
	(0.15)	(0.15)	(0.15)	(0.15)	(0.18)	(0.18)
Station FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Kernel	Triangle	Epanech.	Triangle	Epanech.	Triangle	Epanech.

- Political Incentives: city leaders older than 57 lose the chance of being promoted to the provincial level, generating a discontinuity in incentives (Xi et al. 2017, Wang 2016).
- Auto v.s. Manual Stations: whether the data is automatically reported to the central government by a computer, or manually reported by technicians.

Additional Robustness Checks

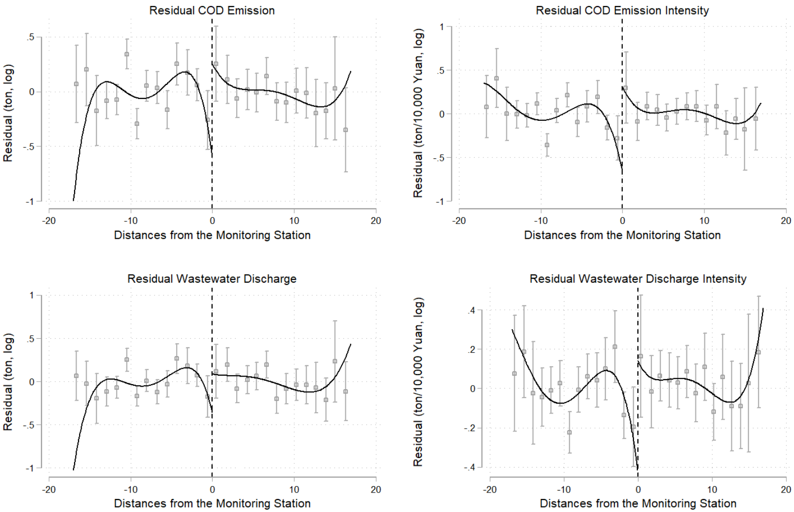
- Alternative ways to calculate S.E.
- Alternative bandwidth selectors
- Placebo stations
- Parametric RD approach
- Use an alternative TFP measure (ACF method proposed by Ackerberg et al. (2015))
- Inferring spillovers between upstream and downstream
- Investigating sorting of firms across monitoring stations

Table 6. Robustness Checks: Impact of Water Quality Monitoring on TFP

	Residual TFP – Polluting Industries		
	(1)	(2)	(3)
Panel A. Alternative Ways to Estimate RD and Standard Errors			
Bias-corrected RD Estimates	0.35**	0.34**	0.38**
	(0.15)	(0.15)	(0.16)
Bias-corrected Robust Estimates	0.35*	0.34*	0.38**
	(0.19)	(0.19)	(0.19)
Panel B. Alternative Ways to Choose Optimal Bandwidth			
Bandwidth Chosen by MSE-Two Selector	0.30**	0.29*	0.25
	(0.15)	(0.15)	(0.17)
Bandwidth Chosen by MSE-Sum Selector	0.31**	0.30**	0.34**
	(0.15)	(0.15)	(0.16)
Bandwidth Chosen by CER-D Selector	0.38**	0.40**	0.43**
	(0.19)	(0.19)	(0.20)
Bandwidth Chosen by CER-Two Selector	0.35**	0.39**	0.48**
	(0.17)	(0.17)	(0.20)
Bandwidth Chosen by CER-Sum Selector	0.37**	0.39**	0.44**
	(0.18)	(0.19)	(0.20)
Panel C. Placebo Tests			
Move Monitoring Stations Upstream by 5km	0.12	0.13	0.11
	(0.16)	(0.16)	(0.16)
Move Monitoring Stations Upstream by 10km	-0.08	-0.09	-0.08
	(0.11)	(0.11)	(0.12)
Move Monitoring Stations Downstream by 5km	0.13	0.15	0.11
	(0.09)	(0.09)	(0.11)
Move Monitoring Stations Downstream by 10km	0.03	0.05	0.07
	(0.16)	(0.15)	(0.17)
Kernel	Triangle	Epanech.	Uniform

▸ Spillover ▸ Sorting

RD Plot: Effects of Water Quality Monitoring on Emissions



RD Estimates of the Impact of Water Quality Monitoring on Emissions

Table 8. RD Estimates of the Impact of Water Quality Monitoring on Emissions

	Conventional Local RD		Bias-Corrected		Bias-Corrected Robust	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: COD Emission						
Residual COD Emission (log)	0.83*	0.75*	0.99**	0.92**	0.99**	0.92*
	(0.44)	(0.42)	(0.44)	(0.42)	(0.49)	(0.47)
Residual COD Emission Intensity (log)	0.55**	0.49*	0.68**	0.62**	0.68**	0.62**
	(0.27)	(0.26)	(0.27)	(0.26)	(0.32)	(0.31)
Panel B: Wastewater Discharge						
Residual Waste Water Discharge (log)	0.39	0.39	0.49	0.50	0.49	0.50
	(0.33)	(0.35)	(0.33)	(0.35)	(0.40)	(0.42)
Residual Waste Water Discharge Intensity (log)	0.34*	0.33*	0.42**	0.41**	0.42*	0.41*
	(0.20)	(0.20)	(0.20)	(0.20)	(0.23)	(0.22)
Bandwidth Selector	MSE	MSE	MSE	MSE	MSE	MSE
Obs.	9,888	9,888	9,888	9,888	9,888	9,888
Kernel	Triangle	Epanech.	Triangle	Epanech.	Triangle	Epanech.

▸ Evidence for the government's double standard

Economic Costs of Environmental Regulation

Table 10. Economic Costs of COD Abatement

	Conventional		Bias-Corrected	
	(1)	(2)	(3)	(4)
Panel A. Estimated Effect of Water Quality Monitoring				
Effect on log TFP	0.31**	0.31**	0.35**	0.34**
	(0.15)	(0.15)	(0.15)	(0.15)
Effect on log COD Emission	0.83*	0.75*	0.99**	0.92**
	(0.44)	(0.42)	(0.44)	(0.42)
Effect on log COD Emission Intensity	0.55**	0.49*	0.68**	0.62**
	(0.27)	(0.26)	(0.27)	(0.26)
Panel B. Estimated Economic Costs Estimates:				
TFP Loss if all Polluting Firms are Monitored	26.66%	26.66%	29.53%	28.82%
TFP Loss per 10% COD Emission Abatement	2.49%	2.75%	2.35%	2.46%
TFP Loss per 10% COD Emission Intensity Reduction	3.75%	4.21%	3.43%	3.65%
Total Output Loss if all Polluting Firms are Monitored (billion CNY)	3988.9	3988.9	4599.6	4444.6
Total Output Loss in the Polluting Industry during the 11th Five-Year Plan (billion CNY), A	351.98	390.86	332.60	348.16
Total Output Loss in the Polluting Industry per 2.5% COD Abatement (billion CNY), A	68.64	76.01	64.95	67.91
Total Output Loss in the Polluting Industry per 10% COD Abatement (billion CNY), A	279.79	310.48	264.48	276.77
Total Output Loss in the Polluting Industry per 2.5% COD Abatement (billion CNY), B	242.91	269.00	229.85	240.34
Total Output Loss in the Polluting Industry per 10% COD Abatement (billion CNY), B	990.2	1098.8	936.0	979.5
Kernel	Triangle	Epanech.	Triangle	Epanech.
Gross Output Value in the Polluting Industry in 2006 (billion CNY), A	10975.7			
Gross Output Value in the Polluting Industry in 2015 (billion CNY), B	38844.9			

- Between 2006 and 2010, China's surface water regulation program led to a 2.5% yearly decrease in COD emissions. Our back of the envelope calculation suggests that such a COD reduction associates with a GDP loss of $>$ 200 Billion Yuan.

Details of the Calculation

Conclusion

- Good environment comes at a cost, especially in the developing countries.
  - The efficiency loss and economic costs caused by environmental regulations are not trivial.
- However, we need more parameters (such as WTP for environment) to judge whether China's current environmental regulations are too aggressive or not.
  - Currently an under-explored area (Ito and Zhang, 2016).

Thank you!

Appendix

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Anecdotal Evidence

Internal document from a prefecture city government in Dec 2017, ordering the temporary shut down of a list of polluting firms, until the readings of the three monitoring stations in its jurisdiction meet the national surface water quality standard. ▸ Back

昆山市两减六治三提升专项行动领导小组办公室

昆 263 办〔2017〕186 号

关于对吴淞江赵屯（石浦）等 3 个断面所属流域工业企业实施全面停产的紧急通知

昆山开发区、昆山高新区、花桥经济开发区管委会，各镇人民政府，市水利局、环保局，水务集团：

近期我市自动监测数据显示，我市国省考断面水质较差，达标形势严峻，尤其是赵屯断面（劣V类）、振东渡口断面（劣 V 类）、千灯浦口断面（V类）均无法达到国省考要求。

为确保我市国省考断面达到国家下达 2018 年度考核目标要求，决定对吴淞江赵屯（石浦）等 3 个断面所属流域工业企业（企业名单附后）自 2017 年 12 月 25 日起至 2018 年 1 月 10 日期间实施全面停产，到期视水质情况，决定是否延期；请相关区镇通知相关企

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Water Quality Monitoring Stations in China

- Three types of stations:
  - **State-controlled stations**
  - Local water quality monitoring stations
  - Special monitoring stations placed downstream to selected factories
- Location choice considerations for state-controlled stations:
  - Cover the country's major rivers, lakes, and reservoirs.
  - Mainly based on hydrological characteristics.
  - NOT based on the location of existing polluting firms, in order to be nationally representative.
  - Try to locate near existing hydrological stations, in order to share certain facilities and data.

Back

Details of TFP Construction

- Problem with OLS estimates of TFP based on CD functions: selection and simultaneity biases.
  - Selection: firms with higher capital stock are less likely to exit the market given the same productivity shock.
  - Simultaneity: positive productivity shocks are observed by firms, but not the econometrician, and will affect input levels.
- Olley and Pakes (1996) address both issues
  - Address simultaneity issues by using investment to proxy for unobserved time-varying productivity shock.
  - Address selection issues by using survival probabilities.
- Key parameters are gross output (to get VA), employment and wages, capital stock, and investment.
- Our Olley-Pakes TFP measure is constructed based on Brandt et al. (2012) using the Annual Survey of Industrial Firms (ASIF) dataset from 2000 to 2007. We made slight changes to the estimations of some key parameters to improve the accuracy of productivity measurement in the ASIF dataset, as suggested by Yang (2015).

Spillovers between Upstream and Downstream?

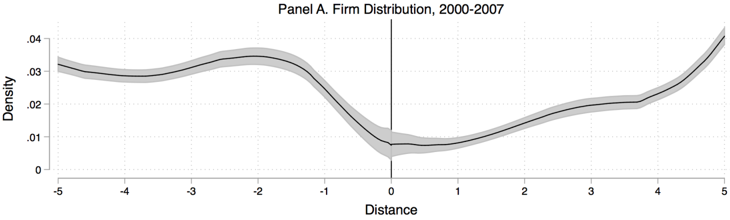
Table 5. RD Estimates using Placebo Downstream Firms

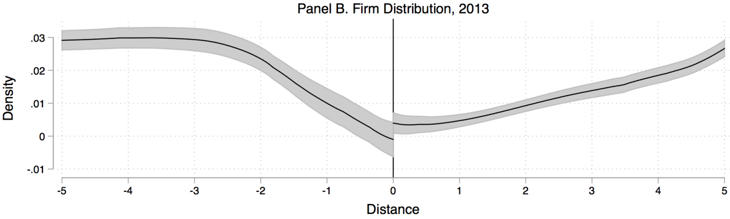
	Polluting Industries			Non-Polluting Industries		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Water Quality Monitoring and TFP						
TFP (log) - Polluting Industries	0.36	0.44*	0.26	-0.18	-0.20	-0.13
	(0.23)	(0.26)	(0.29)	(0.16)	(0.15)	(0.18)
Panel B: Water Quality Monitoring and Residual TFP						
TFP (log) - Polluting Industries	0.48**	0.52**	0.61***	0.13	0.11	0.14
(Station and Industry FE Absorbed)	(0.20)	(0.21)	(0.23)	(0.13)	(0.11)	(0.12)
Obs.	4,435	4,435	4,435	8,001	8,001	8,001
Kernel	Triangle	Epanech.	Uniform	Triangle	Epanech.	Uniform

- For each downstream firm, find a best match in pre-2003 period that is not within the 10-km circle, and use the match firms as placebo downstream firms to run the same RD using post-2003 data.
- Coefficients slightly larger than baseline, suggesting a modest positive spillover between upstream and downstream polluting firms. So our findings are likely underestimations.

Back

Firm Distribution near the Monitoring station





Data-Driven Density Test

Table 5. Density Tests for Sorting Using Local Polynomial Density Estimation

	(1)	(2)	(3)	(4)
Panel A. All Firms, Obs = 6582				
T	0.36	0.21	-2.37	0.36
P>|T|	0.72	0.83	0.02	0.72
Bandwidth Left	2.47	1.97	6.17	2.47
Bandwidth Right	2.01	1.97	6.17	2.01
Panel B, Young Firms, Obs = 2825				
T	0.73	1.30	-1.02	0.08
P>|T|	0.47	0.19	0.31	0.93
Bandwidth Left	2.68	2.00	3.81	2.68
Bandwitdth Right	1.94	2.00	3.81	2.00
Bandwidth Selector	Each	Diff	Sum	Comb

- Data-driven Manipulation Tests on Firm Density: Cattaneo et al. (2016).
- No evidence for sorting, likely due to the fact that these firms are large, and costly to move.
    - Even if there exists sorting among young firms (less costly to sort), that is not driving our results, because all the gap in TFP come from old firms. Back

Double Standards by the Government

Table 7. Channels: RD Estimates on other Measures

	Conventional Local RD		Bias-Corrected RD		Bias-Corrected Robust	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Output Related						
Revenue	-0.09	-0.09	-0.19	-0.18	-0.19	-0.18
(log)	(0.25)	(0.28)	(0.25)	(0.28)	(0.32)	(0.34)
Value-Added	0.04	0.02	-0.05	-0.07	-0.05	-0.07
(log)	(0.22)	(0.23)	(0.22)	(0.23)	(0.28)	(0.29)
Profit	4.47	4.36	5.48	5.36	5.48	5.36
(10 million yuan)	(4.07)	(3.88)	(4.07)	(3.88)	(5.58)	(5.37)
Panel B. Input Related						
Employees	-0.16	-0.14	-0.22	-0.19	-0.22	-0.19
(log)	(0.16)	(0.16)	(0.16)	(0.16)	(0.21)	(0.21)
Investment	-1.72	-0.60	-2.03	-0.34	-2.03	-0.34
(10 million yuan)	(1.77)	(2.06)	(1.77)	(2.06)	(2.13)	(2.46)
Intermediate Input	-0.18	-0.16	-0.28	-0.26	-0.28	-0.26
(log)	(0.25)	(0.27)	(0.25)	(0.27)	(0.33)	(0.33)
Panel C. Policy-Related and RD						
Tax	-0.59	-0.70	-0.76	-0.87*	-0.76	-0.87
(log)	(0.49)	(0.53)	(0.49)	(0.53)	(0.61)	(0.63)
Waste Discharge Fee	-1.15**	-1.07**	-1.41***	-1.32**	-1.41**	-1.32**
(log)	(0.51)	(0.53)	(0.51)	(0.53)	(0.57)	(0.60)
Panel D. Porter Hypothesis						
R&D	-0.06	-0.17	-0.16	-0.28	-0.16	-0.28
(log)	(0.39)	(0.46)	(0.39)	(0.46)	(0.58)	(0.62)
Kernel	Triangle	Epanech.	Triangle	Epanech.	Triangle	Epanech.

- As shown in the previous slide, downstream firms emit more.
- However, in the production dataset, we see that downstream firms pay much less for emission fee (punishment).
- These two pieces of evidence combined together point to the government imposing double standards.

Details of the Back of Envelope Calculation

Intuition:

- We have two samples drawn from the same population (manufacturing firms in China), with different sampling strategies.
  - The ASIF dataset stratifies on revenue.
  - The ESR dataset stratifies on COD emission.
- We have ATEs from each sample separately, we want to link them to each other.
- Within each sample, we explore the heterogeneity w.r.t. its stratifying variable, and then extrapolate the ATEs to the population. This allows us to get the ATEs for TFP and for COD for the entire population.
- Therefore, we get the TFP loss caused by per unit of COD reduction. By linking this number to the overall COD reduction in each year, we know the total GDP loss of water regulation.

Back

Details of the Back of Envelope Calculation

The ATEs we get from the two samples can be written as conditional expectations based on the sampling strategies:

$$TFP_{ATE}|Revenue \geq 5million = E(TFP_1 - TFP_0|Revenue \geq 5million);$$

$$COD_{ATE}|COD \geq x = E(COD_1 - COD_0|COD \geq x)$$

The ATEs on TFP and COD over the entire distribution are:

$$\begin{aligned} &Prob(Revenue \geq 5million) \cdot TFP_{ATE}|Revenue \geq 5million \\ &+Prob(Revenue < 5million) \cdot TFP_{ATE}|Revenue < 5million; \end{aligned}$$

and

$$\begin{aligned} &Prob(COD \geq x) \cdot COD_{ATE}|COD \geq x \\ &+Prob(COD < x) \cdot COD_{ATE}|COD < x \end{aligned}$$

where

$$Prob(Revenue \geq 5million) = \frac{N_{ASIF}}{N}, Prob(Revenue < 5million) = 1 - \frac{N_{ASIF}}{N};$$

$$Prob(COD \geq x) = \frac{N_{ESR}}{N}, Prob(COD < x) = 1 - \frac{N_{ESR}}{N}$$

Details of the Back of Envelope Calculation

Exploiting heterogeneity within the samples, we find that the gaps disappear when the stratifying variables become small (but still above the sampling cutoffs). Assuming continuity in the heterogeneous treatment effects, we have:

$$TFP_{ATE}|Revenue < 5million = 0$$

and

$$COD_{ATE}|COD < x = 0$$

Plugging these into the previous equations, we get:

$$MRS = \frac{TFP_{ATE}}{COD_{ATE}} = \frac{TFP_{ATE}|Revenue \geq 5million}{COD_{ATE}|COD \geq x}$$

Which is the TFP loss associated with per unit COD abatement in the universe of Chinese manufacturing firms.

Back