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The consequences of spatially differentiated water pollution regulation in China[☆]

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ABSTRACT

This paper studies the consequences of China's recent water pollution regulation. We find evidence that the regulation reduces pollution-intensive activity in highly regulated areas. Relative to the locations where regulations are more stringent (downstream cities), locations where regulations are less stringent (upstream cities) attract more water-polluting activity. As polluting activity concentrates upstream, a larger proportion of the river and more poor residents are exposed to high levels of pollution.

1. Introduction

Since 1980, many regions in China have experienced severe water quality degradation that threatens to undermine the nation's quality of life progress associated with 30 years of unprecedented economic growth (Ebenstein, 2012). In 2005, China's national government explicitly addressed the water pollution challenge by specifying in the 11th (2006–2010) Five-Year Plan (FYP) quantitative emission-reduction targets for chemical oxygen demand (COD), a major water pollutant.[1] More

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[1] COD is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals, such as ammonia (Tchobanoglous and Schroeder, 1985). COD is similar in function to biochemical oxygen demand (BOD). The latter is a standard measure of the organic pollutant content of water and has been used as a measure of water quality (e.g., Magat and Viscusi, 1990; Laplante and Rilstone, 1996; Sigman, 2002; Gray and Shadbegian, 2003; Shimshack and Ward, 2008; Chakraborti and McConnell, 2012; Rassier and Earnhart, 2015; Chakraborti, 2016; Greenstone and Hanna, 2014; Lipscomb and Mobarak, 2017).

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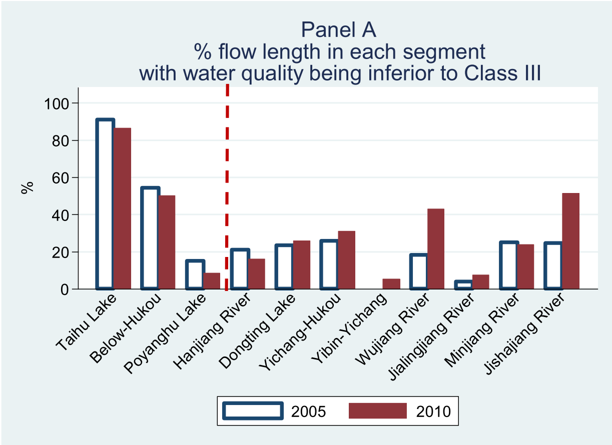
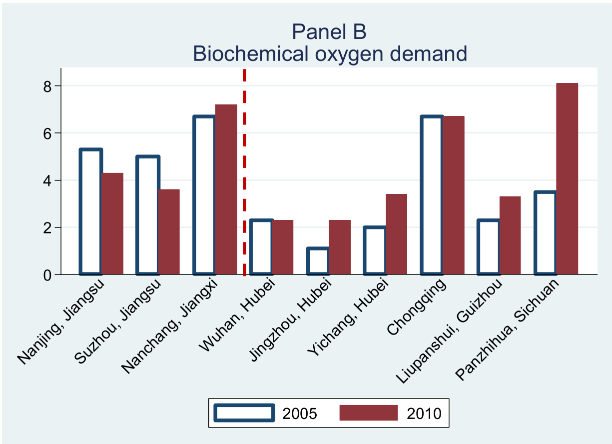


Notes: The graph shows the percentage of flow length in each segment that has a water quality inferior to Class III (not acceptable for drinking use) in the years 2005 and 2010. Class IV water is acceptable for industrial use, but direct contact with skin should be avoided; Class V water is acceptable for irrigation only; water that has a quality worse than Class V is unsuitable for all purposes. The order of the segments is arranged according to their distances to Shanghai, where the river meets the sea. *Taihu Lake*, *Below-Hukou*, and *Poyanghu Lake* segments belong to the downstream part of the river. The dashed line divides the river to the upstream and downstream sections (corresponds to 900 km from Shanghai).



Notes: The graph shows the concentration of BOD for 9 major cities along the main and major tributary streams of the Yangtze River. The data were obtained from *Environmental Yearbooks* (2006 and 2011), which report the concentration of BOD at the water station level in 2005 and 2010. The BOD level in each city in each year is the average of the concentrations of BOD of all of the water stations located in the city. The order of the cities is arranged according to their distances to Shanghai. Nanjing, Suzhou, and Nanchang are the downstream cities. The dashed line divides the river to the upstream and downstream sections (corresponds to 900 km from Shanghai).

Fig. 1. The Yangtze River's water quality time trends.
Data source: The Ministry of Water Resources (http://www.cjw.gov.cn/zwzc/bmgb/).

polluted provinces were subject to higher COD reduction targets. The government also tied compliance with these targets to local officials' chances of promotion. This provided an incentive for local officials to make efforts to meet this target goal (Kahn et al., 2015). During the 11th FYP period, over 82 billion yuan were invested to abate industrial water pollution.[2]

The Yangtze River Basin contains a major proportion of the nation's water-polluting industrial activity. The eleven provinces located in the basin are responsible for nearly half of the nation's COD emissions. The water quality of the Yangtze River is important because the river now provides drinking water for almost 500 million people, and upon the completion of

[2] The data were obtained from the Environmental Statistical Yearbook 2011.

the South-to-North Water Transfer Project, this number will increase to approximately 800 million.[3] In 2011, the central government published a report stating that, according to the COD emissions estimated by local governments,[4] all of the provinces located in the Yangtze River Basin achieved their COD reduction targets. However, other metrics suggest that the Yangtze River's water pollution continues to be a major challenge.

According to the data from the Ministry of Water Resources (MWR),[5] total emissions of industrial wastewater in the Yangtze River increased from 20.4 billion tons in 2005 to 22.7 billion tons in 2010. In addition, the river's flow length of water not acceptable for drinking use increased from 27% in 2005 to 33% in 2010. This increase in the proportion of dirty water was driven by a significant deterioration of water quality in the upstream segments of the river and a surprisingly small improvement in water quality in the downstream segments (Panel A of Fig. 1). The concentration of biochemical oxygen demand (BOD), which is similar in function to that of COD, also increased in almost all of the major upstream cities between 2005 and 2010 (Panel B of Fig. 1). The upstream segments contain more than 80% of the total flow length of the river as well as nearly 55% of the total residents of the basin.[6]

Why did the water quality of the Yangtze River deteriorate over time despite a major regulatory effort to reduce total COD emissions? We argue that a major determinant of this trend is China's recent environmental policy. Similar to the case of the U.S Clean Air Act, this regulation's intensity varies across space and time. The different stringency levels of water pollution regulation imposed on localities along the Yangtze River caused the concentration of water-polluting production to shift from the lower to the upper end of the river, leaving a larger proportion of the river and more (poor) residents exposed to higher levels of pollution.

To study the effects of the regulation, we construct two new measures of regulatory stringency. The first measures the extent to which each city must reduce the COD during the 11th FYP period. The second measure is constructed based on word counts in official policy documents. We argue that this word count is a proxy for the government's desire to reduce pollution. We find solid evidence that China's recent water pollution regulation reduces pollution-intensive activity in highly regulated areas. We find that an increase in the regulation stringency by 0.1 standard deviation decreases the total output value of water-polluting industries by 4–5% or approximately 4.3 billion yuan from the mean in 2005. The upstream cities, which have much looser environmental regulations, attract more water-polluting activities, causing pollution production to shift toward the upper end of the river. In this sense, we provide evidence of “pollution havens” within China. Previous studies on the spatial transfer of water pollution in China focused on the economic activity concentrated on different sides of provincial borders (Cai et al., 2016a; Kahn et al., 2015).

Research on water pollution regulation has emphasized that monitoring and enforcement of regulation are critical to improving water quality (Gray and Shimshack, 2011). In addition, inter-jurisdictional coordination in environmental protection also plays an important role (Sigman, 2002; Cai et al., 2016a; Lipscomb and Mobarak, 2017). Empirical evidence from the U.S. and Canada shows that water pollution regulation has significant effects on the production and reporting activities of firms in water-polluting industries (e.g., Magat and Viscusi, 1990; Laplante and Rilstone, 1996; Shimshack and Ward, 2008; Chakraborti and McConnell, 2012; Rassier and Earnhart, 2015; Chakraborti, 2016). Evidence from developing countries on the effects of water pollution regulation is relatively limited. Greenstone and Hanna (2014) suggest that poor implementation and enforcement of the water pollution regulations in India may explain why these regulations had no measurable benefits. Lipscomb and Mobarak (2017) present evidence of strategic siting of polluting activities near borders by local governments in Brazil and highlight the importance of building collaboration in Brazilian river basins to reduce water pollution. In our case, regulation may not lead to an improvement in either overall water quality or the Chinese population's quality of life if policymakers ignore the fact that spatially differentiated regulation stringency transfers water-polluting activities to areas that are more vulnerable to pollution emissions.

Section 2 of this paper describes the features of China's recent environmental policy. Section 3 presents the regression specification for testing for local regulation's impact on industrial concentration. Section 4 introduces the data. Section 5 reports the regression results. Section 6 concludes.

[3] The South-to-North Water Transfer Project aims to channel 44.8 billion cubic meters of fresh water annually from the Yangtze River to the north through three canal systems. This project was started in the early 1950s. By 2014, more than $79 billion had been spent, making this project one of the most expensive engineering projects in the world. For more details, please see: http://finance.ifeng.com/a/20140514/12327492_0.shtml.

[4] The COD discharge was not directly measured by the central government. Instead, the discharge was estimated by local government officials using an industry-specific formula that converted production activities to pollutants. The estimation was first done at the county level. The numbers were then reported to the provincial government for review and aggregation. Each provincial government then reported its total estimated COD discharges to the central government; see Cai et al. (2016a) for more details.

[5] As a government department, the Ministry of Water Resources is responsible for establishing and implementing rules and regulations pertaining to the utilization of water resources. Besides monitoring the water quality of major rivers and lakes, the main functions of the MWR include dam construction and management, flood and drought control, as well as the conservation of soil and water. The data on water quality and pollution emissions of the MWR were independently collected and reported (Dong, 2013). The MWR's website is http://www.cjw.gov.cn/zwzc/bmgb/.

[6] The proportion of the population in the upstream section was calculated based on each province's population size of current residents in 2015, which was obtained from the National Bureau of Statistics. In 2015, the total population in the 11 provinces located in the Yangtze River Basin was 587.68 million. A total of 321.28 million people live in the six upstream provinces.

2. Institutional background

2.1. An overview of water pollution control policy in China

Since 1978, China has established a decentralized system to control and prevent pollution. The central government sets the general environmental targets, while local governments are responsible for setting and enforcing the detailed environmental regulations (Van Rooij and Lo, 2010; Zheng and Kahn, 2013). The Ministry of Environmental Protection (MEP), the counterpart of the Environmental Protection Agency in the United States, is responsible for setting national environmental policies and regulations and for monitoring regulation enforcement of local bureaus of environmental protection (BEPs). At the subnational level, BEPs are in charge of enforcing the environmental protection regulations in their own jurisdictions. BEPs are controlled by the local governments.

Before 2005, local officials had weak incentives to fulfill the environmental targets set by the central government. Such officials with career concerns recognized that their promotion chances within the Chinese Communist Party hinged primarily on achieving economic growth (Zhou, 2008). Therefore, they often overlooked environmental violations by industrial plants in return for generating local fiscal revenue, creating jobs, and promoting economic growth (Jia, 2012; Jiang et al., 2014). As a result, while China's central leaders increasingly focused on environmental protection, as shown by the content of the 9th FYP in 1995 and its successor in 2000, environmental degradation continued (Vennemo et al., 2009).

To ensure local government's compliance with the environmental targets written in the 11th FYP in 2005, the central government revised the evaluation criteria by tying the pollution targets to local officials' chances of promotion. To encourage localities to comply with the national policy, the central government announced that local officials' performance with respect to COD (water) and sulfur dioxide (air) reductions would outweigh all of the other achievements (MEP, 2007). Success in fulfilling the pollution reduction mandates would improve their promotion prospects. In contrast, local officials who failed to satisfy the pollution targets would be removed from office (State Council, 2007).

2.2. Water pollution regulation and the 11th Five-Year Plan

In the 11th FYP, the central government's water-pollution criteria only targeted COD emissions (National People's Congress, 2006).[7] In March 2006, the central government announced a binding target, namely, that the national COD emissions must be reduced by 10% or a total of 1.41 million tons by the end of 2010. In August 2006, the MEP and the National Development and Reform Commission of China[8] jointly published the "11th Five-Year National Total Emissions Control Plan of the Major Pollutants" to specify the pollution reduction mandates at the provincial level. Each province's COD reduction target was based on a number of factors, such as provincial economic growth, industrial structure, current pollution intensity, and the potential of pollution reduction. In general, more polluted provinces and those experiencing faster economic growth were subject to higher reduction mandates. (Table A1 shows the provincial COD reduction mandates.)

In November 2006, the MEP issued a within-province allocation guideline dictating how much each city must reduce its COD (MEP, 2006). In particular, the guideline gives an explicit formula for the calculation of the total COD reduction mandate (measured in tons) for city c in province p from 2005 through 2010:

$$\Delta COD_{c,05-10} = \Delta COD_{p,05-10} \times \frac{P_{c,2005}}{\sum_{j=1}^{J} P_{j,2005}}. \tag{1}$$

In equation (1), the first term $\Delta COD_{p,05-10}$ is province p's COD reduction mandate; the second term represents the proportion of province p's COD emissions in 2005 that is contributed by industries located in city c, while $P_{c,2005}$ is the total industrial COD emissions in city c in 2005 and J represents the number of cities in the province.

To achieve the pollution reduction targets, local officials generally used two instruments: the *ex-ante* emission permits for industrial plants and *ex-post* monitoring and punitive measures (e.g., warnings, fines, and suspension of business licenses). In order to obtain emission permits, industrial plants were required to meet tougher emission standards, install higher-capacity (more expensive) pollution control equipment, and perform more frequent maintenance. In addition to the mandated adoption of clean technology, another common strategy of local governments was to directly shut down heavily polluting plants or limit new factories in dirty industries from locating there by using land use controls.[9] All of these pollution reduction measures affect a firm's production cost and therefore the spatial distribution of the polluting activity. For example, an increase in the production costs of water-polluting plants would lead them to reduce production. If production costs become

[7] Based on our conversations with local BEP officials, the MEP has focused on COD for two reasons. First, the central government views COD as the most harmful water pollutant. Second, the MEP and local BEPs are also more experienced in monitoring and reducing COD emissions than other major pollutants.

[8] The National Development and Reform Commission of China (NDRC) is a macroeconomic management agency under the Chinese State Council. The NDRC's main function is to devise policies for China's social and economic development.

[9] For example, according to the city government work reports, in 2007, Nanjing, Jiangsu Province, and Hangzhou, Zhejiang Province, shut down a total of 136 and 57 polluting plants, respectively.

extremely high (e.g., for land acquisition), the owners may decide to shut down the plant and re-invest in other localities with weaker environmental regulations.

In China, capital-intensive industrial production can relocate rapidly thanks to the industrial parks established by local governments to attract investment (e.g., Wang, 2013; Alder et al., 2016; Chen et al., 2017a). By 2006, almost every prefecture or above-level city had its own industrial park. These industrial parks provide basic infrastructure, such as paved roads, highways, sewage systems, and the supply of utilities. Together, these investments greatly facilitate the relocation of industrial firms. Based on our interviews with firms and local officials, it often took only two years from the moment the investment decision was made until a new plant operated at full capacity. The "relocation" of the production activity of an industry can also happen without moving plants. For example, in response to more stringent regulations, investors could downsize investment and inject their money into the existing plants located elsewhere. In addition, increasing the scale of production of a typical manufacturing plant in China can be rapidly completed because the equipment utilization rates of Chinese firms, on average, are very low (Shen and Chen, 2017).

3. A framework for testing the impact of local regulation on the distribution of industrial activities

The main objective of our empirical analysis is to identify the effect of water pollution regulations on local industrial production activity. We posit that the production of water-polluting industries will decrease more in localities with more stringent regulations relative to localities with relatively lax regulation stringency. The time and spatial variations of the stringency of water pollution regulation of the 11th FYP provide an opportunity for implementing a difference-in-difference (DD) strategy. Specifically, before 2006, the regulation stringency was almost uniform across cities. After 2006, some cities were assigned a more stringent COD reduction mandate and hence adopted stricter water pollution regulations. We compare the production of water-polluting industries in the highly stringent cities before and after 2006 with the corresponding change in the low-stringency cities. The DD estimation specification is presented in equation (2):

$$y_{ct} = \varphi R_c \times Post_t + \alpha_c + \delta_t + \varepsilon_{ct}, \tag{2}$$

where y_{ct} is a measure of the activity of water-polluting industries in city c in year t; R_c is a measure of regulation stringency in city c; $Post_t$ is a dummy variable that indicates the post-treatment period, i.e., $Post_t$ equals one $\forall t > 2006$; α_c represents city fixed effects, capturing city c's time-invariant characteristics, such as climate, geographic features, and natural endowment; δ_t represents year fixed effects, capturing all of the yearly factors that are common to all of the cities (e.g., macro shocks, business cycles, and monetary and fiscal policies); and ε_{ct} is the error term.

A possible concern with the DD estimation strategy is that some time-varying city characteristics may be correlated with $R_c \times Post_t$ and may bias the estimate of φ. For example, an important determinant of firm location choice is the agglomeration effect (e.g., Duranton and Puga, 2004; Zeng and Zhao, 2009). City characteristics, such as input-output linkages between buyers and suppliers, the efficiency of labor markets, and the quality of the learning environment, may evolve over time, causing the extent of productivity externalities to differ over years. However, given the wide range of city variables that affect productivity externalities, it is difficult to include all of the relevant factors in the specification (2). In addition, cities with more stringent environmental regulations may witness faster labor cost increases due to better implementation of the *New Labor Law* since 2007, which would probably lead to an over-estimation bias of φ in equation (2).

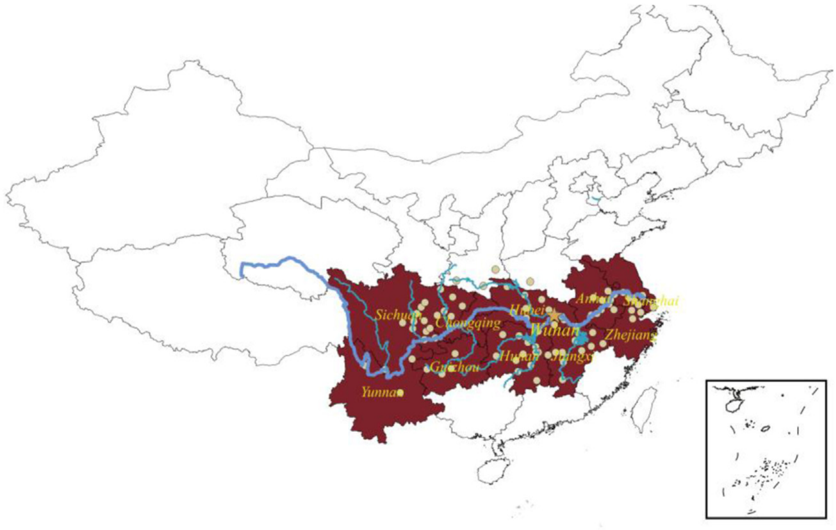
To overcome this problem, we exploit the fact that the effect of regulation differs between water-polluting industries and non-water-polluting industries. We construct a balanced panel data set. The unit of observation in this case is a two-digit industry in a city in a year. We then estimate a DDD equation based on equation (3):

$$y_{ict} = \varphi R_c \times Post_t \times Dirty_i + \eta_{ct} + \kappa_{it} + \lambda_{ic} + e_{ict}, \tag{3}$$

where y_{ict} is a measure of the activity of industry i in city c in year t; $Dirty_i$ is a dummy variable indicating the water-polluting industries, i.e., $Dirty_i$ equals one if industry i is a water-polluting industry. A major advantage of the DDD specification (3) is that it allows us to include city-year fixed effects, η_{ct}. This vector controls for all of the time-varying and time-invariant city characteristics, e.g., productivity spillovers, input prices, local public policies, workforce quality, and wage rates for workers with different skills. In addition, in equation (3), we also include industry-year effects, κ_{it}, which capture all of the time-varying and time-invariant industry characteristics, e.g., industry-specific technology and government's industry policies. Furthermore, we include industry-city fixed effects, λ_{ic}, to allow industry production to differ across cities. In (3), e_{ict} represents the error term. Within the same industry (city), the error terms in different years may be serially correlated. The error terms of different industries in the same city may be spatially correlated. To control for potential spatial and serial correlations of the error term, the standard errors are two-way clustered by city and by industry.

4. Data and variable construction

Our sample contains 85 cities in 11 provinces located in the Yangtze River Basin (Fig. 2). Among them, 83 are prefecture-level cities, and 2 are provincial-level cities (i.e., Shanghai and Chongqing). During our study period of 2003–2009, these 85 cities accommodated more than one third of the Chinese population and produced 30% of the national Gross Domestic



Notes: The graph maps the eleven provinces in the Yangtze River Basin. The dots represent the 85 cities in our sample. The star represents Wuhan in Hubei Province. The graph also shows the main and all of the major tributary streams of the Yangtze River.

Fig. 2. The Yangtze River basin.

Product (GDP). In our sample, Lijiang in Yunnan Province is the most upstream city. Shanghai is where the river meets the sea. Wuhan in Hubei Province is the middle point of the river, with the river distance to Shanghai being 900 km.[10] We define the cities located downstream relative to Wuhan as the downstream cities, and those located upstream relative to Wuhan (including Wuhan) as the upstream cities. As shown in Panel A of Table 1, compared with the upstream cities, the downstream ones were much richer and more polluted to begin with (with the average GDP per capita of 29,850 yuan per person and the average total output value of the selected water-polluting industries of 249 billion yuan). The upstream section of the river contains more than 80% of the total flow length of the river as well as nearly 55% of the total residents of the basin. For our empirical analysis, we construct a balanced panel data set in which each observation represents a two-digit industry in a city in a year, with information on production activity, the city's regulation stringency, and other relevant variables.

4.1. Constructing two measures of local water regulation stringency

4.1.1. The city-level COD reduction mandate

Environmental regulations are multi-dimensional and are often difficult to quantify (Shadbegian and Wolverton, 2010). Recognizing this challenge, economists have used discrete regulatory categories, such as whether a U.S. county does not comply with the Clean Air Act's standard (e.g., Henderson, 1996; Greenstone, 2002), or whether a Chinese city has “Two Control Zone” status designated by the Air Pollution Prevention and Control Law of 1998 (e.g., Hering and Poncet, 2014; Cai et al., 2016b).

To measure water pollution regulation stringency, most previous studies have relied on *ex-post* regulation variables, such as actual levy fees (Dean et al., 2009) and actual spending on pollution abatement (Gray and Shadbegian, 2003; Zhang et al., 2011). An exception is Wu et al. (2017); they studied the effect of the provincial COD reduction mandate (an *ex-ante* regulation measure) on the location decisions of new polluting firms. For the estimation of the regulation effect on firms' production decisions, the *ex-ante* regulation measures are superior to the *ex-post* ones as they are less likely to be affected by changes in the production activities of polluting firms in response to the changing regulatory stringency.[11]

[10] For more details on the geography of the Yangtze River, see http://www.cjw.gov.cn/zjzx/cjyl/.

[11] Table A3 shows that, starting in 2006, the provincial COD mandates of the 11th FYP were positively correlated with the provincial-level regulation measures used in previous studies, such as annual levy fees per pollution facility, annual spending on water pollution abatement, and the total annual investment in water pollution abatement.

Table 1
Summary statistics.

Panel A: City-level characteristics	All cities	Downstream	Upstream
River distance to Shanghai		<900 km	>900 km
COD reduction mandate	0.540	0.953	0.368
(10,000 tons)	[0.830]	[1.226]	[0.517]
Observations	85	25	60
Avg. environment-related text proportion (2006, 2007, 2008)	2.319	2.881	2.092
(%)	[1.012]	[1.225]	[0.820]
Observations	80	23	57
Avg. environment-related text proportion (2004, 2005)	1.360	1.393	1.346
(%)	[0.566]	[0.581]	[0.565]
Observations	79	24	55
Output value of water-polluting industries in 2005	994.056	2490.058	370.722
(100 million yuan)	[2224.135]	[3666.323]	[481.166]
GDP per capita in 2005	1.617	2.985	1.048
(10,000 yuan)	[1.524]	[2.144]	[0.562]
Population in 2005	475.820	451.548	485.934
(10,000 persons)	[376.909]	[282.400]	[411.657]
River distance to Shanghai	1.353	0.494	1.710
(1000 km)	[0.740]	[0.234]	[0.561]
Observations	85	25	60

Panel B: Production activities of the water-polluting industries

City's total output value in each industry in each year, 100 million yuan in 2010 price level

	Water-polluting industries			
	Pulp and paper production		Chemical materials and products	
	Mean	S.D.	Mean	S.D.
2003	108.62	272.83	484.84	1101.30
2004	136.55	363.08	660.16	1524.94
2005	161.32	424.53	832.73	1919.59
2006	187.53	498.77	1006.12	2363.82
2007	225.17	596.59	1252.40	2823.88
2008	282.47	686.16	1391.86	2803.76
2009	241.18	569.92	1249.58	2303.04
Total	191.83	505.89	982.53	2213.42

Panel C: Production activities of the non-water-polluting industries

City's total output value in each industry in each year, 100 million yuan in 2010 price level

	Non-water-polluting industries							
	Electronic appliances		Special appliances		Electric appliances		Office appliances	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
2003	775.09	3274.13	176.11	435.97	329.08	939.19	80.12	301.05
2004	1145.95	5161.61	220.37	628.85	494.01	1464.84	103.94	414.08
2005	1366.22	6020.02	244.84	654.76	571.07	1603.72	135.73	515.75
2006	1637.36	7028.64	317.88	803.27	746.56	2066.37	166.44	621.50
2007	1961.69	8490.31	406.39	1020.43	972.69	2580.31	191.03	644.15
2008	2001.25	8849.22	548.62	1384.59	1303.22	3106.41	225.83	660.73
2009	1666.77	7996.46	456.22	1110.05	1132.24	2581.48	174.18	534.99
Total	1507.76	6919.08	338.63	918.33	792.70	2180.26	153.90	540.73

Notes: Standard deviations are presented in parentheses.

Based on the provincial-level COD reduction mandates of the 11th FYP and the within-province allocation rule described by formula (1) in Section 2.2, we calculate the extent to which each city must reduce the COD. Ideally, each city's COD reduction mandate can be calculated by multiplying the total COD reduction mandate of the province that contains the city by the city's proportion of the province's total COD emissions in 2005. However, in practice, the COD emissions are not directly measured but are estimated from production activities by local government officials. As such, we use the information on the production activities of water-polluting industries in 2005 from the Annual Survey of Industrial Firms to estimate each city's COD emission proportion. (See Section 4.2 for more details on this database.) Specifically,

$$\Delta COD_{c,05-10} = \Delta COD_{p,05-10} \times \sum_{i=1}^{39} \mu_i \frac{\text{output value of industry } i \text{ in city } c}{\text{output value of industry } i \text{ in province } p}. \tag{4}$$

The second term on the right-hand side of the equation is a measure of the city's proportion of the province's total output value of the water-polluting firms. Specifically, we calculate a weighted average of the city's proportion of the province's total output value across all of the 39 two-digit industries, using each industry's proportion of total industrial COD emissions, μ_i, as the weight. (For example, the pulp and paper production industry's weight is 0.3237; the electronic appliance manufacturing industry's weight is 0.0034.)

Panel A of Table 1 reports the summary statistics of the constructed city-level COD reduction mandate. For all of the cities in the sample, the average COD reduction mandate is 5400 tons, and the standard deviation is 8300 tons. Compared with the upstream cities, the downstream ones have much higher COD reduction mandates (9530 tons on average).

4.1.2. The environmental related text proportion of each city's government work report

Provincial leaders may impose lower reduction targets on their favored city leaders (Jia et al., 2015; Chen et al., 2017b). Moreover, the actual environmental effort of local officials may not be fully captured by how much the city must reduce the COD. To address the concern that the constructed city-level COD reduction mandate may still measure the actual regulation stringency with an error, we develop an alternative stringency measure based on official documents to quantify the government's desire to reduce pollution.

In China's political system, government work reports are some of the most important official documents prepared by each level of government to summarize their jurisdictions' social and economic achievements in the past year (e.g., GDP growth, fiscal revenue growth, industrial development, average resident's income, unemployment, foreign investment, exports, fixed asset investment, and environment protection) and to lay out the work plan and detailed targets for the coming year. In the first quarter every year, city governments report the details of their work reports to the National People's Congress and the Chinese People's Political Consultative Conference. Generally, the content of the work reports reflects the work focuses of the city governments. The achievements are all based on hard statistics. The work plan provides guidelines for the lower-level governments, and the detailed targets are expected to be strictly fulfilled by the lower-level government officials. The city government also faces pressure from the local public who demand that the promises written in the work report be fulfilled. The proportion of text related to a specific policy in a city's government annual work report is commonly used by the public to measure the amount of actual effort that local officials have exerted in fulfilling the targets.[12]

Of the 85 cities in the sample, we were able to find the 2004 work reports for 81 cities, the 2005 work reports for 81 cities, the 2006 work reports for 83 cities, the 2007 work reports for 83 cities, and the 2008 work reports for 84 cities. Most of the cities posted their government work reports to the Internet, and this allows for easy downloading. Nonetheless, we obtained approximately 20% of the reports in the sample either by filing official applications to individual city governments or through personal connections with local officials.

From the work report text, we select all of the sentences that contain environment (*huanjing*), energy consumption (*nenghao*), pollution (*wuran*), emission reduction (*jianpai*), and environmental protection (*huanbao*) as environment-related sentences. For each year, we then calculate each city's environment-related text proportion as the ratio of the total words in the environment-related sentences relative to the total words in that year's work report.

Based on the timeline of the water pollution regulation of the 11th FYP discussed in Section 2.2, we measure each city's regulation stringency using *the average of the environment-related text proportion of the city's work reports published after 2006*; i.e., the 2006, 2007, and 2008 work reports.[13] For the purpose of conducting a placebo test, we also calculate the average of the environment-related text proportions of the 2004 and 2005 work reports. As shown in Panel A of Table 1, before 2006, on average, local governments used approximately 1.36% of the space in their annual work reports to elaborate on the implementation and enforcement of local environmental regulations, and this proportion is not statistically different between the downstream and upstream cities. After 2006, the environment-related text proportion increased to 2.32% on average, and the increase is much higher in the downstream cities than in the upstream ones.

4.2. Firm data

We use the total industrial output value of firms in an industry as a proxy for the industry's production. The dependent variable is the log of the total output value per industry per city per year.[14] The information is generated from the Annual

[12] For example, see: http://www.langya.cn/lyzt/2012lh/bgjd/201203/t20120301_104063.html, http://www.dzwww.com/shandong/sdnews/201301/t20130126_7952322.htm, and http://news.xinhuanet.com/politics/2011-03/11/c_121176376.htm.

[13] For example, the 2006 work reports were published in January 2007.

[14] The number of firms is an alternative proxy for industrial production activities. We consider that the total output value superior to the number of firms as the latter can be also affected by other factors, such as the merging and acquisition of firms in the industry. Although not reported in our paper, the results of the regressions using the number of firms as the dependent variable are quite similar to the results of the regressions using the log of the output value as the dependent variable.

Survey of Industrial Firms (ASIF) conducted by China's National Bureau of Statistics (NBS) for the period from 2003 to 2009.[15]

The ASIF contains basic firm information (name, address, industry classification, ownership, etc.) and major financial variables (annual output value, annual sales, assets, etc.).[16] From the firm-level data, we calculate the total annual output value in every two-digit industry in each city in each year from 2003 through 2009.[17] We use two-digit industries because the water-polluting industries are identified by the two-digit classification.

We identify two water-polluting manufacturing industries: pulp and paper production, and chemical materials and products. As the major COD emitters, firms in these two industries account for 32% and 12% of the total industrial COD emissions, respectively, and therefore, they are the major targets of local regulators (Table A2). Within these two water-polluting industries, approximately 30% of the national output value was produced in the 85 cities along the river, and this proportion has remained quite stable over the years.[18]

We selected four non-water-polluting industries: electronic appliances manufacturing, special appliances manufacturing, electric appliances manufacturing, and office appliances manufacturing. These four industries caused only a small proportion of industrial COD emissions (together less than 1%). Their Yangtze River's proportions are comparable to those of the selected water-polluting industries and have remained stable from 2003 through 2009 (see Table A2).

Panels B and C of Table 1 report the summary statistics of the total output value for these six two-digit industries in the 85 cities from 2003 through 2009. All of the price variables in this paper have been converted to constant 2010 price levels using the provincial-level fixed price index reported by the NBS of China.

Fig. 3 shows the cumulative distributions of both water-polluting and non-water-polluting industries in 2003, 2006, and 2009. The horizontal axis measures the river length between each city and Shanghai. We divide the cities in our sample into 20 equal-sized distance boxes. The cities located closer to Shanghai are contained in the boxes labeled with smaller numbers. The vertical axis measures the cumulative fraction of the total output value from box one to the corresponding distance box on the horizontal axis. The production in both types of industries is spatially widespread across cities along the Yangtze River. From 2003 through 2006, the cumulative distribution functions of both types of industries remained almost unchanged. However, starting in 2006, relative to the non-water-polluting industries, the cumulative distribution function of the water-polluting industries shifted right over time. Fig. 4 further shows that this increase in the proportion of water-polluting production in the upstream area is caused by a greater increase of the production size in the upstream cities, relative to the downstream cities. In the next section, we test whether the regulation's spatial differential stringency was responsible for the spatial re-distribution of polluting activity.

5. Does polluting industrial activity respond to water regulation severity?

5.1. Main results

The DD estimation results corresponding to specification (2) are reported in Table 2. For both regulation measures, the interaction term is negative and significant. Together with the estimates of the coefficients for the calendar year dummies, the results in columns 1 and 2 suggest that on average, the production activity per city of the water-polluting industries has been increasing over the years, and the increase is larger in the cities with a lax regulation environment than in the cities with more stringent regulations. In the regression corresponding to column 3, we replace the regulation measure with the dummy variable indicating whether the city is located in the upstream area. Consistent with the patterns shown in Figs. 3 and 4, the results in column 3 show that the water-polluting production activity increased more in the upstream cities than in the downstream cities after 2006. However, for the non-water-polluting industries, we do not find a significant increase in the upstream areas, relative to the downstream areas.

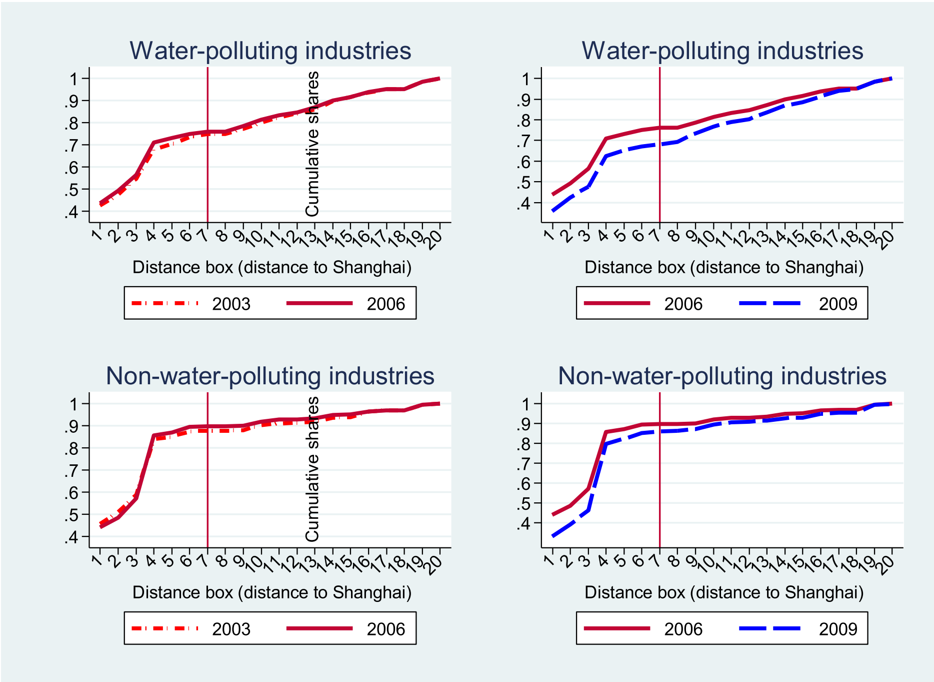
Our main results are based on the DDD estimation (3), which overcomes the endogeneity problem due to omitted time-varying city characteristics. The DDD estimation results are presented in Table 3. The first three columns present the results of the regressions that use the COD reduction mandate as the stringency measure. As shown in column 1, we find that the triple

[15] The survey covered all of the state-owned enterprises and those non-state-owned enterprises with annual sales of five million Renminbi or more in mining, manufacturing, and the production and distribution of electricity, cooking gas, and water. The sample selection rule of the ASIF would affect our estimation if the regulation effect differs between very small private firms and the other firms. We will explore the heterogeneity in the regulation effect across different types of firms to shed light on this. For the period from 2007 to 2009, state-owned-enterprises with annual sales of less than five million are no longer included. Our main results are robust if we drop all state-owned-enterprises with annual sales of less than five million before 2007.

[16] The NBS collects this dataset in order to compute GDP numbers. For this purpose, every surveyed firm is required to file an annual report of production activities and accounting and financial information with the NBS. As the NBS has implemented standard procedures in calculating the national GDP since 1995 and has strict double-checking procedures for surveyed firms, information contained in the ASIF should be quite reliable (Cai and Liu, 2009). In addition, since the information in the ASIF cannot be used by other government agencies, such as tax or environmental authorities, firms do not have clear incentives to misreport.

[17] Before aggregating the firm-level data to the industry-city-level data, we deleted those observations with missing or zero annual output values, resulting in a loss of less than 1.5% of the data.

[18] Table A2 shows that firms producing agricultural products and byproducts are also major COD emitters. For this industry, the Yangtze River's proportion of the national total output value increased by 25% from 2006 to 2009, which may be caused by a large shift of production activities from elsewhere in China to the cities in our sample. As we are interested in the change of the distribution of industrial production activities inside the Yangtze River Basin, we chose not to select this industry as a water-polluting industry. Our main results remain similar if we included this industry as a water-polluting one.



Notes: The horizontal axis measures river length between each city and Shanghai, where the river meets the sea. We divide the cities in our sample into twenty equal-sized distance boxes. The cities located closer to Shanghai are contained in the boxes labeled with smaller numbers. The vertical axis measures the cumulative fraction of the total output value from box 1 to the corresponding distance box on the horizontal axis. The red solid line divides the river to the upstream and downstream sections (corresponds to 900 km from Shanghai).

Fig. 3. The Spatial distribution of water-polluting and non-water-polluting production along the Yangtze River.

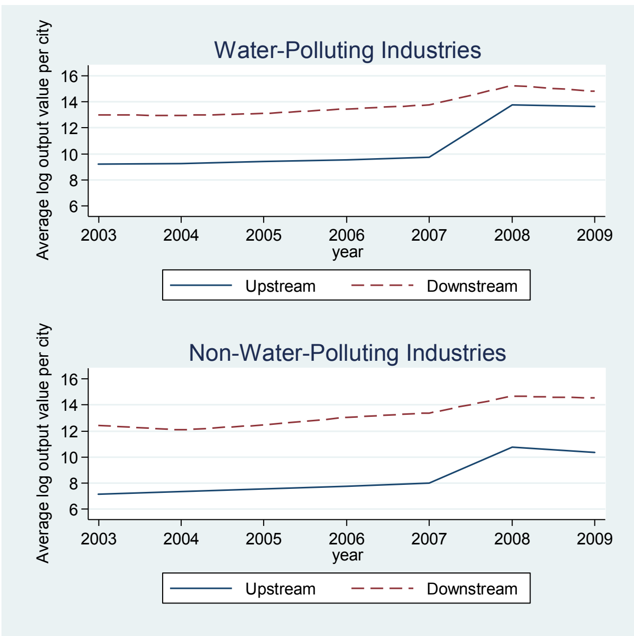


Fig. 4. Time trends of water-polluting and non-water-polluting production activities along the Yangtze River.
Source: National Bureau of Statistics Annual Survey of Industrial Firms.

Table 2
The effect of pollution regulation on local industrial activity based on a DD estimation strategy.

The Dependent variable: log (total output value in each industry in each city in each year)				
	Water-polluting industries			Non-water-polluting industries
	(1)	(2)	(3)	(4)
COD reduction mandate* Post 2006	−1.171***			
	(0.231)			
Avg. environment-related text proportion * Post 2006		−1.096***		
		(0.273)		
Upstream* Post 2006			1.547***	0.572
			(0.507)	(0.483)
Year dummy 2004	0.021	0.068	0.021	0.028
	(0.042)	(0.079)	(0.042)	(0.135)
Year dummy 2005	0.180***	0.229**	0.180***	0.294*
	(0.060)	(0.100)	(0.060)	(0.176)
Year dummy 2006	0.354***	0.351***	0.354***	0.599***
	(0.113)	(0.120)	(0.113)	(0.130)
Year dummy 2007	1.243***	3.125***	−0.482	0.465
	(0.178)	(0.621)	(0.395)	(0.376)
Year dummy 2008	4.516***	6.403***	2.791***	2.810***
	(0.539)	(0.893)	(0.506)	(0.464)
Year dummy 2009	4.287***	6.161***	2.562***	2.482***
	(0.588)	(0.922)	(0.550)	(0.428)
City fixed effects	Yes	Yes	Yes	Yes
Observations	1190	1120	1190	2380
R-squared	0.749	0.748	0.746	0.718

Notes: ***p < 0.01, **p < 0.05, and * p < 0.1. Heteroskedasticity-robust standard errors in parentheses are clustered at the city level. The year 2003 is the omitted category.

interaction term is negative and statistically significant. These results suggest that the 11th FYP reduces production among water-polluting facilities in highly regulated localities. The economic magnitude of the regulation effect is large: an increase of the COD reduction mandate by 1000 tons (about 10% of the standard deviation) leads to a decrease of the total output value of the water-polluting industries by 4.35%, representing a decrease of 4.3 billion yuan from the mean in 2005 (i.e., 99.4 billion yuan).

The coefficient in column 1 captures the average regulation effect on the selected water-polluting industries. To examine the regulation effect for each water-polluting industry, we introduce two triple interaction terms in column 2, which allows us to test for the regulation's effect on the pulp and paper production and the chemical materials and products industries separately. For both industries, the regulation effects are negative and significant. The magnitude of the effect is slightly larger for the chemical industry than for the paper industry.

Table 3
The effect of pollution regulation on local industrial activity based on a DDD estimation strategy.

The Dependent variable: log (total output value in each industry in each city in each year)						
	(1)	(2)	(3)	(4)	(5)	(6)
COD reduction mandate* Post 2006* Dirty	−0.435**		−0.441**			
	(0.194)		(0.199)			
COD reduction mandate* Post 2006* Pulp and paper		−0.320**				
		(0.142)				
COD reduction mandate* Post 2006* Chemical		−0.549***				
		(0.161)				
Avg. environment-related text proportion * Post 2006* Dirty				−0.464***		−0.515***
				(0.179)		(0.189)
Avg. environment-related text proportion * Post 2006* Pulp and paper					−0.415***	
					(0.142)	
Avg. environment-related text proportion * Post 2006* Chemical					−0.514***	
					(0.154)	
Log GDP per capita (t-1)* Dirty			−2.952**			−2.803**
			(1.282)			(1.219)
Log city population (t-1)* Dirty			19.172			23.829*
			(12.172)			(12.481)
City-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City-industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3570	3570	3570	3360	3360	3360
R-squared	0.942	0.942	0.942	0.944	0.944	0.945

Notes: ***p < 0.01, **p < 0.05, and * p < 0.1. Heteroskedasticity-robust standard errors in parentheses are two-way clustered by city and by industry.

Table 4
Testing for pre-treatment trends.

The Dependent variable: log (total output value in each industry in each city in each year)		
	(1)	(2)
COD reduction mandate* Year Dummy 2004* Dirty	0.017	
	(0.079)	
COD reduction mandate* Year Dummy 2005* Dirty	0.075	
	(0.112)	
COD reduction mandate* Year Dummy 2006* Dirty	0.106	
	(0.114)	
COD reduction mandate* Year Dummy 2007* Dirty	0.105	
	(0.109)	
COD reduction mandate* Year Dummy 2008* Dirty	−0.631**	
	(0.287)	
COD reduction mandate* Year Dummy 2009* Dirty	−0.630**	
	(0.291)	
Avg. environment-related text proportion * Year Dummy 2004* Dirty		0.060
		(0.087)
Avg. environment-related text proportion * Year Dummy 2005* Dirty		0.118
		(0.091)
Avg. environment-related text proportion * Year Dummy 2006* Dirty		0.064
		(0.111)
Avg. environment-related text proportion * Year Dummy 2007* Dirty		0.060
		(0.110)
Avg. environment-related text proportion * Year Dummy 2008* Dirty		−0.618**
		(0.293)
Avg. environment-related text proportion * Year Dummy 2009* Dirty		−0.654**
		(0.273)
City-year fixed effects	Yes	Yes
Industry-year fixed effects	Yes	Yes
City-industry fixed effects	Yes	Yes
Observations	3570	3360
R-squared	0.942	0.945

Notes: ***p < 0.01, **p < 0.05, and * p < 0.1. Heteroskedasticity-robust standard errors in parentheses are two-way clustered by city and by industry. The year 2003 is the omitted category.

To address the concern that there might still be omitted variables that vary simultaneously across time, cities, and industries, we further include the city's GDP per capita and population size in year (t-1), interacted with *Dirty*. Column 3 of Table 3 shows that the regulation effect remains unchanged. In addition, the polluting activities have decreased in cities with greater initial GDP per capita.[19]

The last three columns in Table 3 report the results of the regressions that use the environment-related text proportion as the stringency measure. The main findings remain quite similar. An increase in the average environment-related text proportion by 0.1 percentage points (about 10% of the standard deviation) leads to a decrease of the total output value of the water-polluting industries of approximately 4.64%.

5.2. Testing for variation over time

A potential concern regarding the DDD estimation (see equation (3)) is that the change in regulation stringency after 2006 may have summarized in part the efforts that local governments made prior to 2006, and that the change in the distribution of industrial activities after 2006 was really caused by a pre-existing trend. To address this concern, we estimate all of the lags and leads of the environmental regulation effect. The specification is given by:

$$y_{ict} = \sum_{j=-2}^{3} \varphi_j R_c \times Year_{2006+j} \times Dirty_i + \eta_{ct} + \kappa_{it} + \lambda_{ic} + \varepsilon_{ict}. \tag{5}$$

In (5), $Year_{2006+j}$ represents the calendar year dummies. The year 2003 is the omitted category. The standard errors are two-way clustered by city and by industry.

Table 4 presents the results. We find that in the pre-treatment period (i.e., before 2006), the estimates are positive and insignificant (relative to the base year 2003). In 2008, the regulation initially had a negative and statistically significant effect,

[19] We also estimate specifications in which we replace the log term with the linear and quadratic terms of GDP per capita. The coefficient for the linear term is negative, while that for the quadratic term is positive. The turning point is 83,100 yuan per person, which is above the maximum GDP per capita in our sample of 77,100 yuan per person.

and the effect remained in 2009. The results suggest that the effect of the water-polluting regulations of the 11th FYP on the production activities of the water-polluting industries was not immediate. It took time for both local officials and polluting firms to implement and respond to regulations.

5.3. Other robustness checks

5.3.1. Alternative regulation stringency measure

Both the COD reduction mandate and the environment-related text proportion may measure the actual regulation stringency with errors. As a robustness check, we predict the latent regulation stringency from our two stringency measures using principal factor analysis (Anderson and Rubin, 1956) and re-run the main regressions as was done in Tables 3 and 4. The results exhibit a fairly similar pattern to the main results shown in Tables 3 and 4. We do not report the results in the paper for the sake of saving space, but they are available upon request.

5.3.2. Placebo test using government work reports published before 2006

We use the average of the environment-related text proportions of each city's 2004 and 2005 work reports as the stringency measure and re-run the regressions in Tables 3 and 4. The results show that the environmental efforts that local governments made prior to 2006 has no impact on the distribution of industrial activities after 2006. Table 5 reports the results.

5.4. Heterogeneous treatment effects

Tables 3 and 4 report the average effect of water-pollution regulation on the production activities of all firms. We next test whether these effects vary as a function of the firm's attributes such as its ownership status and size. The state-owned enterprises (SOEs) usually have social goals, such as improving local employment other than maximizing profit. Therefore, compared with private firms, SOEs are less cost-sensitive and hence may respond less to environmental regulations. To provide empirical evidence for this, we first divide the firm sample into SOEs and private firms and then construct the industry-city-year-level aggregate numbers for these two subsamples. Columns 2 and 3 in Panel A of Table 6 report the results for SOEs and private firms, respectively, using the COD reduction mandate as the stringency measure. We find that the regulation effect was small and statistically insignificant for SOEs.

Foreign firms are often bound by more stringent environmental regulation in their home countries and hence are insensitive to the change in environmental regulation in China (Cai et al., 2016b). We divide the firm sample into domestic and foreign firms to explore how the regulation effect differs between these two types of firms. Columns 4 and 5 show the results. The effect is economically and statistically significant for domestic firms. For foreign firms, the effect was negative but insignificant. Cai et al. (2016b) find that the environmental effect differs across foreign firms with different origin countries. Firms from countries with good environmental protection are insensitive to regulations in China. However, for firms from countries with less stringent environmental regulations than China, local environmental regulation is an important factor determining investment. As our data do not allow us to distinguish firms by their origin countries, the estimate in column 5 represents the average regulation effect, which may be slightly dominated by the latter type of foreign firm.

Table 5
A placebo test.

The Dependent variable: log (total output value in each industry in each city in each year)		
	(1)	(2)
Avg. environment-related text proportion 0405* Post 2006* Dirty	0.078 (0.243)	
Avg. environment-related text proportion 0405* Year Dummy 2004* Dirty		0.288 (0.251)
Avg. environment-related text proportion 0405* Year Dummy 2005* Dirty		0.232 (0.201)
Avg. environment-related text proportion 0405* Year Dummy 2006* Dirty		0.314 (0.279)
Avg. environment-related text proportion 0405* Year Dummy 2007* Dirty		0.039 (0.185)
Avg. environment-related text proportion 0405* Year Dummy 2008* Dirty		0.499 (0.441)
Avg. environment-related text proportion 0405* Year Dummy 2009* Dirty		0.320 (0.363)
City-year fixed effects	Yes	Yes
Industry-year fixed effects	Yes	Yes
City-industry fixed effects	Yes	Yes
Observations	3318	3318
R-squared	0.948	0.948

Table 6
Testing for heterogeneous regulation effects.

Panel A

The Dependent variable: log (total output value in each industry in each city in each year)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	All	SOE	Private	Domestic	Foreign	Large	Small
COD reduction mandate* Post 2006* Dirty	−0.435**	0.030	−0.459**	−0.463**	−0.339	−0.244	−0.391**
	(0.194)	(0.204)	(0.201)	(0.210)	(0.234)	(0.241)	(0.163)
City-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3570	3570	3570	3570	3570	3570	3570
R-squared	0.942	0.872	0.938	0.934	0.892	0.918	0.907

Panel B

Dependent variable: log (total output value in each industry in each city in each year)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	All	SOE	Private	Domestic	Foreign	Large	Small
Avg. environment-related text proportion * Post 2006* Dirty	−0.464***	−0.276*	−0.407**	−0.452**	−0.446**	−0.393	−0.572***
	(0.179)	(0.155)	(0.177)	(0.196)	(0.219)	(0.250)	(0.210)
City-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3360	3360	3360	3360	3360	3360	3360
R-squared	0.944	0.876	0.940	0.936	0.891	0.916	0.910

Notes: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Heteroskedasticity-robust standard errors in parentheses are two-way clustered by city and by industry.

The ASIF surveyed all of the SOEs and those private firms with annual sales of five million yuan or more. To shed light on how this sample selection rule affects our estimation, we divide the firm sample into two subsamples based on firms' annual sales. The large firms have annual sales above the sample median in each year. The results are presented in columns 6 and 7 in Panel A of Table 6. The effect is not statistically different between large and small firms. Nevertheless, compared with large firms, the regulation effect for the smaller ones is more significant, both economically and statistically. Given that the regulation effect is larger for private and small firms, the sample selection rule of the ASIF is likely to cause an underestimation of the regulation effect.

As shown in Panel B of Table 6, the results of the regressions that use the environment-related text proportion as the stringency measure exhibit a similar pattern to those shown in Panel A of Table 6.

5.5. Regulation effects on other water-polluting industries

Besides the two selected industries, the production activities of some other industries also heavily pollute the water. For example, the ferrous metal smelting and pressing industry ("ferrous metal") is responsible for 21% of total industrial petroleum emissions and 18% of total industrial lead emissions; the petroleum and nuclear fuel processing industry ("petroleum & nuclear fuel") is responsible for 13.4% of total industrial petroleum emissions and 37% of total industrial phenol emissions; and the non-ferrous metal smelting and pressing industry ("non-ferrous metal") contributes 28% of total industrial mercury emissions and 29% of total industrial lead emissions.[20] While the ferrous metal industry is among the top six in the list of industries with the highest COD emissions, the petroleum & nuclear fuel and the non-ferrous metal industries have relatively small COD discharge proportions (Table A2).

We examine the regulation effect on the production activities of these major emitters of the non-targeted water pollutants. The results are reported in Table 7. Panel A uses the COD reduction mandate as the regulation stringency measure; Panel B uses the environment-related text proportion as the stringency measure. The regulation effect is statistically and economically significant for the ferrous metal industry. However, the production activities of the petroleum & nuclear fuel industry were insensitive to the water pollution regulation of the 11th FYP. For the non-ferrous metal industry, the results diverge between two stringency measures. While the effect of the COD reduction mandate is small and insignificant, an increase of the environment-related text proportion has a negative and significant impact. Compared with the COD reduction mandate, the environment-related text proportion likely captures the regulation efforts in reducing a wide variety of water pollutants.

There are two reasons that may explain the variation of the regulation effect across water-polluting industries. First, since the 11th FYP targeted only COD, local officials may be more tolerant of polluting activities of the industries emitting non-

[20] Ammonia-nitrogen (NH) is another major water pollutant. Plants in the pulp and paper production industry and chemical materials and products industry are the major NH emitters.

Table 7
Effects of regulation on the spatial concentration of other water-polluting industries.

Panel A				
The Dependent variable: log (total output value in each industry in each city in each year)				
	(1)	(2)	(3)	(4)
COD reduction mandate* Post 2006* Paper & chemical	−0.435**			
	(0.194)			
COD reduction mandate* Post 2006* Ferrous metal smelting and pressing		−0.359***		
		(0.107)		
COD reduction mandate* Post 2006* Petroleum and nuclear fuel processing			0.056	
			(0.120)	
COD reduction mandate* Post 2006* Non-ferrous metal smelting and pressing				−0.038
				(0.133)
City-year fixed effects	Yes	Yes	Yes	Yes
Industry-year fixed effects	Yes	Yes	Yes	Yes
City-industry fixed effects	Yes	Yes	Yes	Yes
Observations	3570	2975	2975	2975
R-squared	0.942	0.945	0.928	0.930

Panel B				
The Dependent variable: log (total output value in each industry in each city in each year)				
	(1)	(2)	(3)	(4)
Avg. environment-related text proportion * Post 2006* Paper & chemical	−0.464***			
	(0.179)			
Avg. environment-related text proportion * Post 2006* Ferrous metal smelting and pressing		−0.349***		
		(0.111)		
Avg. environment-related text proportion * Post 2006* Petroleum and nuclear fuel processing			0.314	
			(0.205)	
Avg. environment-related text proportion * Post 2006* Non-ferrous metal smelting and pressing				−0.485***
				(0.164)
City-year fixed effects	Yes	Yes	Yes	Yes
Industry-year fixed effects	Yes	Yes	Yes	Yes
City-industry fixed effects	Yes	Yes	Yes	Yes
Observations	3360	2800	2800	2800
R-squared	0.944	0.946	0.929	0.932

Notes: ***p < 0.01, **p < 0.05, and * p < 0.1. Heteroskedasticity-robust standard errors in parentheses are two-way clustered by city and by industry.

targeted water pollutants. In fact, Kahn et al. (2015) find that China's recent target-based environmental responsibility scheme pushed local politicians to focus on COD progress while providing weak incentives for them to target other harmful pollutants, such as petroleum, mercury, and phenol. Second, firms in certain industries may be less footloose and more resource-dependent than firms in the paper and chemical industries and are thus less sensitive to regulation.

5.6. The spatial transfer of water-polluting activity

Given that the regulatory stringency increased more in the downstream cities than in the cities located upstream, our estimation results suggest a spatial transfer of water pollution from the lower to the upper end of the river. In this subsection, we provide additional supporting evidence for the spatial transfer of water-polluting activity. [21]

5.6.1. Regulation effects on entry and exit

A major form of the spatial transfer of polluting activity in response to increased local regulation is that once regulation increases, the old polluting firms in the downstream areas exit the sample, and there is an increase of new infant firms in the upstream areas in the same industry. Using the information on a firm's year of opening, we calculate the number of new infant and old firms in each industry in each city in each year. Old firms are restricted to those that reported their year of opening to be 2000 or some time earlier than 2000. We run regressions according to specification (3) to examine how new infant and old firms respond to regulation change. The regression results are reported in Table 8. We find that the triple interaction terms are all negative. For new infant firms, the estimates are statistically significant. The results indicate that cities with looser environmental regulations (the upstream cities) attracted more new firms in water-polluting industries. Meanwhile, old firms exited from cities with tougher regulations (the downstream cities).[22]

[21] In order to show direct evidence that polluting plants moved from the lower to the upper end of the river in response to the differentiated regulation stringency, ideally we need to observe the migration of individual firms. However, in the ASIF, if a firm moves, its identifier will be changed, which makes it impossible to track migrating firms.

[22] Since firms with sales revenue less than 500 million are not included in ASIF, exit of old firms here implies a firm's shutdown or decreasing scale below the threshold.

Table 8
The effect of pollution regulation on new and old firms.

Dependent variable	log (number of new firms +1)		log (number of old firms +1)	
	(1)	(2)	(3)	(4)
COD reduction mandate* Post 2006* Dirty	−0.091*		−0.052	
	(0.046)		(0.033)	
Avg. environment-related text proportion * Post 2006* Dirty		−0.066***		−0.049
		(0.006)		(0.042)
City-year fixed effects	Y	Y	Y	Y
Industry-year fixed effects	Y	Y	Y	Y
City-industry fixed effects	Y	Y	Y	Y
Observations	3570	3360	3570	3360
R-squared	0.770	0.770	0.977	0.977

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Heteroskedasticity-robust standard errors in parentheses are clustered by city and by industry. The unit of analysis is a city/industry/year.

Table 9
The regulation effects on local industrial Activity.

Dependent variable: log (total output value in each industry in each city in each year)				
	(1)	(2)	(3)	(4)
	Downstream	Upstream	Downstream	Upstream
COD reduction mandate* Post 2006* Dirty	0.059	−1.092**		
	(0.134)	(0.488)		
Avg. environment-related text proportion * Post 2006* Dirty			0.033	−0.605**
			(0.132)	(0.289)
City-year fixed effects	Yes	Yes	Yes	Yes
Industry-year fixed effects	Yes	Yes	Yes	Yes
City-industry fixed effects	Yes	Yes	Yes	Yes
Observations	1050	2520	966	2394
R-squared	0.949	0.933	0.954	0.935

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Heteroskedasticity-robust standard errors in parentheses are clustered by city and by industry.

5.6.2. The upstream and downstream samples

If there was no spatial transfer of water-polluting production from the lower to the upper end of the river, we would be less likely to find a large negative effect for the upstream sample given that the upstream areas are relatively clean to begin with (see Fig. 1). We run regressions according to specification (3) using the upstream and downstream samples separately. Table 9 shows that while the effect is small and statistically insignificant for the downstream sample, the regulation effect is negative and statistically significant for the upstream sample. The results suggest that, among the upstream cities, those with less stringent regulations received more polluting activity from firms that would otherwise have chosen to locate in the downstream cities in the absence of regulations.

6. Conclusions

China's recent water regulations have had unintended consequences. To quantify this, we have introduced two new empirical measures of water pollution regulation. These regulatory measures vary across space and time so that some areas are more intensely regulated than others. Similar to the U.S. literature on the unintended consequences of the Clean Air Act (Henderson, 1996; Becker and Henderson, 2000; Greenstone, 2002; Kahn and Mansur, 2013), we have documented that China's water-pollution regulation led to a decline in pollution-intensive activity in highly regulated areas, and such activity may have shifted to less regulated areas. Smaller, privately owned, and domestic firms were more responsive to city level regulations than larger, state-owned, and foreign firms.

In the U.S. case, fewer people are exposed to air polluting sources as large cities increase their regulations relative to less populated areas. In the case of Chinese water pollution, the regulation has failed to prevent polluting activity from increasing in the ***densely populated areas upstream***. Furthermore, as documented by Ebenstein (2012), the cost of the deterioration of water quality is disproportionately borne by Chinese farmers who are unable to access safe drinking water. This means that the damage caused by polluting upstream areas could be even worse, as more than 50% of local residents in these areas are farmers who have fairly low incomes and are more likely to be exposed to water pollution.[23] Since downstream regions in

[23] According to the statistics from the National Bureau of Statistics, in 2015, the rural population proportions of Yunnan, Guizhou, and Sichuan were 56.7%, 58%, and 52.3%, respectively.

most developing countries are usually closer to major sea ports and are thus more developed than upstream regions, our findings have general implications that different environmental regulations may subsequently subject populations in less developed upstream regions to worse situations.

Our findings also suggest that the compliance with the water-pollution regulation of the 11th FYP was imperfect for the upstream provinces despite their local governments claiming that they had achieved the assigned COD reduction targets. In China, COD emissions are self-estimated and self-reported by local governments (Cai et al., 2016a). Therefore, local officials might misreport COD data even though they could face risks of being scrutinized by upper-level governments (Ghanem and Zhang, 2014). As the local governments in the upstream area usually face more pressure to increase GDP growth (Zheng and Kahn, 2013), they should have greater incentives to manipulate pollution data. We will pursue this issue in our future research.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jeem.2018.01.010.

Notes: Heteroskedasticity-robust standard errors in parentheses are two-way clustered by city and by industry. In column (2), the year 2003 is the omitted category.

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