Journal of Comparative Economics 42 (2014) 118–142

Contents lists available at ScienceDirect

Journal of Comparative Economics

journal homepage: www.elsevier.com/locate/jce

The determinants of pollution levels: Firm-level evidence from Chinese manufacturing

Liangliang Jiang [a], Chen Lin [b], Ping Lin [a,*]

[a] Lingnan University of Hong Kong, Hong Kong
[b] Faculty of Business and Economics, University of Hong Kong, Hong Kong

ARTICLE INFO

Article history:
Received 30 July 2012
Revised 24 July 2013
Available online 15 August 2013

JEL classification:
F4
K4
O1

Keywords:
Pollution
Local protection
Law enforcement
FDI

ABSTRACT

Jiang, Liangliang, Lin, Chen, and Lin, Ping—The determinants of pollution levels: Firm-level evidence from Chinese manufacturing

Using a large, unique, firm-level dataset from the Chinese manufacturing sector, we study important factors that are related to emission intensity for three pollutants in China – sulfur dioxide, wastewater, and soot. Our main findings are as follows: (1) compared to state-owned enterprises (SOEs), both foreign-owned firms and domestic public-listed firms exhibit less intensive pollutant emissions; (2) firms in regions with less local protection have lower pollution intensity; (3) better property rights protection is negatively correlated with pollutant discharge over and beyond the national standards; and (4) larger firms, firms in industries that export more, and firms with more educated employees pollute less. These results suggest that China should not target foreign firms more harshly in its effort to reduce industrial pollution. Better institutions in the form of more effective law enforcement and lower entry barriers across regional markets are also means of curbing China's pressing environmental problems during its current stage of economic development. *Journal of Comparative Economics* **42** (1) (2014) 118–142. Lingnan University of Hong Kong, Hong Kong; Faculty of Business and Economics, University of Hong Kong, Hong Kong.

1. Introduction

China has been undergoing a rapid, large-scale economic expansion that has almost no historical parallel. However, its economic miracle has also made it one of the largest polluters in the world. According to a World Bank report, many newly established heavy industry plants in China do not control pollution as effectively as factories in other parts of the world.[1] The deteriorating environmental quality has attracted great attention globally,[2] and there have been rising concerns whether the remarkable growth of China can be sustained in the long run if the pollution continues to worsen. While policymakers are urged

* Corresponding author.
E-mail addresses: liangliangjiang@ln.edu.hk (L. Jiang), chenlin1@hku.hk (C. Lin), plin@ln.edu.hk (P. Lin).

[1] See *The New York Times*, August 26, 2007. The article offers more details from the World Bank report, such that "Chinese steel makers, on average, use one-fifth more energy per ton than the international average. Cement manufacturers need 45% more power, and ethylene producers need 70% more than producers elsewhere." Likewise, "Chinese industry uses 4–10 times more water per unit of production than the average in industrialized nations, according to the World Bank."

[2] In January 2013, Beijing drew global media attention due to being encased in thick smog with air pollution hazard levels (according to standards set by the United States Environmental Protection Agency) soaring. See *The New York Times*, January 30, 2013.

0147-5967/$ - see front matter
http://dx.doi.org/10.1016/j.jce.2013.07.007

to take serious action to tackle the pollution problems, for any policy to be effective, a first and foremost question is about targeting: What kinds of manufacturers tend to pollute more and thus should be regulated more intensively? However, due to the lack of high-quality data, there have been very few studies that systematically investigate the determinants of industrial pollution in China.

This research aims to fill in the gap in the literature by compiling a unique firm-level dataset to empirically explore the factors that are associated with pollution intensity in China's manufacturing sectors. This unique dataset has several appealing advantages: (1) it contains information on pollution emissions at the plant level, enabling us to include a rich set of heterogeneous firm-level characteristics that have to be omitted in the industry- or regional- level analyses; (2) compare with the pollution fee paid by a firm that is often used as a proxy for pollution intensity in previous studies, the quantity of pollutants discharged from each plant recorded in our dataset provides a direct and arguably better measure of pollution[3]; (3) the dataset allows us to examine the determinants of several different types of pollutants, as it has an extensive coverage of pollutants emission information, ranging from waste water (such as chemical oxygen demand and ammonia nitrogen pollutant concentrations), air pollution (such as sulfur dioxide, burned dust, and industrial soot emission concentration), solid waste to noise; (4) unlike other survey data that mostly limits to a specific region of China, this database is nationally representative, covering all of the manufacturing sectors (SIC 4-digit) across all provinces in China; and (5) as the survey on plant pollution was conducted in 2006 and 2007, when China's stock exchanges had well developed and its efforts on property rights protection had also been implemented for a while, it enables us to test the effects of various ownership types (such as public-listed firms) and local governance on pollution.

In particular, we examine how a firm's pollution intensity is related to the following several major factors. The first factor is firm ownership. One debate is about whether the majority of the pollution is produced by the state-owned enterprises (SOEs) or foreign-owned firms. While no one denies that SOEs are a big source of industrial pollution, foreign firms are often blamed as well and sometimes are even accused of deliberately relocating heavy-polluting industries to China.[4] However, defenders of foreign firms argue that multinational enterprises often care about their reputation (a negative image in one country may hurt business opportunities in other countries) and would take more responsibility to protect local environment than domestic firms do. Likewise, public-listed companies are also supposed to take extra corporate social responsibility (CSR) on pollution controls because they are subject to the scrutiny of public investors. A countervailing argument is that since pollution reduction is costly and may eventually harm a firm's profitability, listed-firms may not have strong incentives to pursue the CSR on environmental protection (Friedman, 1970). We empirically examine these competing arguments by comparing six different types of ownership of Chinese manufacturing firms and use the state-owned enterprises (SOEs) as the benchmark group. Our regression results show that both foreign-owned and public-listed companies have lower pollution intensity relative to SOEs.

The second potential factor that affects industrial pollution is local protectionism. Although the national environmental regulations (such as the Pollution Discharge Levy System) have been implemented in China since the 1980s, this system does not give enterprises enough incentives to control their emissions (Florig et al., 1995). It has been well documented in the literature that environmental policies are poorly implemented in developing countries often because of malfunctioned institutions (e.g. Dasgupta, 2000; Bell et al., 2002). In the case of China, in order to maintain local tax revenue, create job opportunities, and promote economic growth, local governments have incentives to support local manufactures (many of which are SOEs) through all kinds of favorable policies, including tolerating their heavy pollution and even protecting them from being penalized for making excessive pollution. For example, Lo et al. (2006) argue that the pervasive "pro-growth" priorities of local governments undermine the implementation of environmental policies in China. A testable hypothesis for our analysis is that firms located at places with stronger local protection will produce more pollution. Our empirical results are consistent with this hypothesis.

Third, we hypothesize that better property rights protection is associated with less pollution intensity. The Coasian theory implies that well-defined property rights can help reduce or even eliminate externalities such as pollution (Coase, 1960, 1990). A well-defined and enforced legal system enables individuals to sue the polluting parties more effectively, thereby discouraging pollution.[5] The Chinese government recently renewed its efforts to strengthen property rights policies and law enforcement to address the weak institution issue. Therefore, it is of particular interest to examine the effect of property rights protection on pollution. We offer evidence that is consistent with theoretical predictions that better property rights protection is negatively associated with pollution intensity, especially when the pollutants discharge level is over the national standard.

Finally, we examine the relationship between pollution and some other firm performance and characteristics, such as firm exporting activities, firm size, and staffs' education level. There is some evidence in the literature suggesting that these factors could also matter for industrial pollution. For example, a recent study by Holladay (2010) finds that exporters generate significantly less pollution than their non-exporting competitors in the same industry, even after controlling for productivity. Weersink and Raymond (2007) argue that more educated people tend to be more capable of expressing their

[3] The current levy system functions as a two-part tariff system with a uniform rate for within-standard emissions and increasing rates for above-standard emissions. However, even with a national standard on pollution emission, local authorities can vary the levy level significantly, reducing or even eliminating the discharge fees at the discretion of local regulators under certain inspections (Wang and Wheeler, 2005). This has caused significant variations in pollution discharge fees across regions of China, given identified factory and pollutant emissions. As a result, using pollution fees as a measure of pollutant discharge across China is rather ambiguous and would cause substantial bias in our analysis.

[4] In 2007, the Chinese government found that Unilever China and the China branch of Hitachi Construction Machinery Co. were discharging wastewater with higher chemical content than permitted (*China Daily*, September 17, 2007).

[5] Farzin and Bond (2006) document that high-quality political institutions respond favorably to environmental demands from the population.

voices or appealing through formal institutions when their interests are negatively affected by pollution. Our empirical analysis finds consistent results that smaller firms, firms that export less, and firms with less educated employees tend to have more pollution intensity.

Overall, our results suggest that, to effectively cut industrial pollution in China, environmental regulations should more target SOEs and medium- and small-sized manufactures. Meanwhile, reducing local protectionism and/or improving the legal institution is also a promising direction. It is worth to note that after a series of sensitivity tests, the overall patterns generated from our empirical analyses are generally robust towards alternative sample and model specifications. However, because we cannot completely guard against potential biases resulting from omitted variables or measurement issues due to data limitation, one should be cautious when interpreting our estimates as true causal effects.

Despite of its limitation, this study contributes to the literature in two important ways. First, to the best of our knowledge, this study is among the first to examine the determinants of firm pollution intensity using large-scale firm-level discharges that cover all of the manufacturing industries in China.[6] We contribute to the small but growing literature on the determinants of industrial pollution in China (e.g. Wang and Jin, 2002; Dean and Lovely, 2008; Liang, 2008; Dean et al., 2009), and as mentioned above, we improve over previous studies by using more direct measures of plant-level pollution based on a nationally representative sample. In addition, the paper also supplements the literature on China's environmental regulations (Wang and Wheeler, 2005; Almond et al., 2009),[7] and the literature on the socioeconomic consequences of pollution in China (Ebenstein, 2012).[8] Second, while previous research on industrial pollution mostly focus on the individual effects of trade, ownership or FDI on pollution at the country- or industry-level,[9] we are among the first to systematically examine the effects of all of these factors at the plant level, and add to the literature the effects of local protectionism and property rights protection on industrial pollution. By investigating six different types of firm ownership, we document that foreign-owned firms have less pollution intensity than SOEs. This result is consistent with a few recent studies on Chinese pollution that show the beneficial effects of openness.[10] We also offer new evidence that public-listed companies in China take more social responsibilities on pollution control than SOEs. Using direct measures of industry-level air and water pollution generated by Chinese manufactures from 1995 to 2004, Dean and Lovely (2008) document that Chinese exports are less water pollution-intensive, and generally less air pollution-intensive than Chinese imports.[11] In contrast, we directly calculate the firm-level export ratio, and from a different angel we show the beneficial effects of exporting on environmental quality in China.

The remainder of this paper is organized as follows. The previous section reviews the research on pollution and environmental protection. Section 2 provides institutional background. Section 3 discusses theories on determinants of pollution emission and develops our hypotheses accordingly. Section 4 describes the data. Section 5 presents empirical analysis and results. Section 6 provides additional discussions on data and measurement issues, and Section 7 concludes the paper.

2. Institutional background

The evolution of China's legislation and institutional development on environmental protection can be traced back to 1979, when the state council first proposed that pollution charges be written into the Environmental Protection Law. This is considered a milestone in China's environmental legal system. Following the implementation of the pollution charges across some cities, the state council further issued the *Tentative Provisions on Pollution Charge* (the State Council Order No. 21) in 1982, which defines the purpose behind the formula of the pollution charge and the management of the fund generated by pollution fees. This levy system covered almost all of China by 1996. However, due to the low levy rate, many enterprises have chosen to discharge pollutants directly instead of performing pollution control (such as installing new facilities to reduce pollution). Thus, with the rapid expansion of the manufacturing industries, China's pollution problem has actually become more serious. In 2003, a new pollution charge policy was brought into effect. It not only charges for pollution emissions over the standard, but also within the standard. Furthermore, this new policy covers almost all polluting elements discharged by enterprises ranging from wastewater, and industrial air to solid waste and noise. Since then, the pollution fee has

[6] The only paper we are aware of that also uses nationwide plant-level emission data is by Wang and Wheeler (2005). They estimate an econometric model in which firm-level pollution levy rates and emissions are jointly determined and demonstrate that China's levy system is a significant pollution deterrent.

[7] Wang and Wheeler (2005) document the effectiveness of levy system on pollution control. Almond et al. (2009) assesses the role of heating entitlements set by the Chinese government in its central planning period (1950–1980) and finds that the heating policy causes the total suspended particulates level particularly high in the north China where heating is allowed under the government policy.

[8] Ebenstein (2012) studies pollution across China's river basins and finds that a one-grade deterioration in water quality increases the digestive cancer death rate by 9.7%.

[9] Among the early pioneering studies, Antweiler et al. (2001) and Copeland and Taylor (2004, 2005) find that the overall effect of trade liberalization is beneficial. Similarly, Frankel and Rose (2005) use cross-sectional country data and solve the potential endogeneity problem in previous studies. They find little evidence that foreign trade has a detrimental effect on environment. In another important paper, Javorcik and Wei (2003) find no evidence of the *Pollution Haven Hypothesis* using firm-level data from 25 transitional economies.

[10] Using city-level data for the period from 1996 to 2003, Liang (2008) finds a negative correlation between FDI inflow and air pollution, suggesting that the overall effect of FDI is beneficial to China's environment; Wang and Jin (2002) find similar results and argue that foreign firms pollute less due to energy efficiency and the superior technology they use; Dean et al. (2009) revisit the pollution-haven hypothesis, and document that equity joint ventures in highly polluting industries funded through non-ethnically Chinese countries are not attracted by weak environmental standards, but those funded by ethnical Chinese sources are.

[11] They interpret their results as evidence of the composition effect – a result of trade-induced specialization in China toward clean, labor-intensive processing activities and away from dirty, capital-intensive production – that has favored China's environment.

increased rapidly. From 2003 to 2006, the total pollution fee collected each year has increased from RMB6 billion to RMB14 billion, an average increase rate of about 33% for each year.

In 1988, the State Environmental Protection Agency (SEPA),[12] which is responsible for the implementation of pollution charges, was formed along with many local Environmental Protection Bureaus (EPBs) being set up throughout the nation. Over the past 30 years, many environmental protection organizations besides the EPBs have also been formed at both the national and local (provincial, city, or county) levels. According to the data released by the Ministry of Environmental Protection (MEP), China had established 11,321 environmental protection institutions by the end of 2006, with 393 at the national and provincial levels.[13] Due to the differentiations in economic and technological development across regions and areas, local government and authorities are encouraged to make local regulations and rules that adapt to specific local situations. Of course, these rules and regulations cannot be in conflict with those at the national level. China has established or passed one environmental protection law, 26 environmental individual laws, over 50 environmental protection administrative regulations and over 1600 local environmental decrees and rules.[14] However, even with the relatively complete environmental legal system and growing number of administrative sectors, China is suffering from the poor implementation and enforcement of these laws and regulations. In reality, local government officials can "exercise considerable discretion over how to identify factories as non-compliant, how to prioritize their enforcement efforts and how to enforce compliance" (Tilt, 2007). The interference of local governments has caused substantial ambiguity over how the levy should be implemented in real practice. Some EPBs are also accused of corruption on the distortions in using these pollution discharge fees. Overall, the insufficiency of supervision capacity and the poor law enforcement accompanied by administrative problems have seriously detracted from the effectiveness of local pollution control.

Meanwhile, despite the fact that public participation and information sharing have been greatly promoted by the Chinese government, China's public participation rate on environmental protection is still very low and the information sharing is far from effective or efficient. The Environmental Protection Law clearly stipulates that government should release environmental information to the public, but the majority of local residents are often unaware of the fact that the big construction projects in their neighborhoods might be harmful. The SEPA and many local government environmental protection organizations have opened their own websites to let people access statistical data, news, legal documents, and newly passed protection rules and decrees directly through the Internet. Nonetheless, the real experience of searching through this information shows that pollution data are still very limited to the public and neither detailed nor timely.

3. Hypothesis development

In this section, we develop several hypotheses regarding some important factors that may affect industrial pollution. It is worth noting that, although our discussions are rather exploratory given limited guidance from prior research about the determinants of pollution in China, these hypotheses build a good starting point for our empirical analysis as well as future research.

First, the literature suggests that firm ownership could be a primary determinant of pollution (Talukdar and Meisner, 2001; Wang and Jin, 2002; Wang and Wheeler, 2005). One possible distinction is between domestic firms (especially SOEs) and foreign firms. Intuitively, based on the "Pollution Haven" hypothesis (i.e. polluting industries tend to move from developed countries to less-regulated developing countries), foreign-owned firms may pollute more relative to SOEs. But some empirical studies draw the opposite conclusions, arguing that foreign firms may generate less pollution because of their more advanced technology. For example, based on an analysis of U.S. outbound investment, Eskeland and Harrison (2003) document that foreign enterprises are more energy efficient and use cleaner types of energy than state-owned factories. Wang and Jin (2002) also find that foreign firms in China pollute less than domestic firms thanks to better energy efficiency and the superior technology they use. Besides, multinational firms may also have stronger incentives than SOEs to control pollution, worrying that a negative image in one country (such as polluting the host country) could dampen the firm's business opportunities in other countries. While it is unclear *a prior* whether foreign firms tend to pollute more or less than SOEs, we propose the following two competing hypotheses:

Hypothesis 1a. Other things being equal, foreign-owned enterprises have lower pollution intensity (pollutant discharge per unit of sales) than SOEs.

Hypothesis 1a′. Other things being equal, foreign-owned enterprises have higher pollution intensity (pollutant discharge per unit of sales) than SOEs.

Another dimension of ownership we attempt to explore is comparing public-listed firms with (unlisted) SOEs. In general, firms have both disincentives and incentives to control pollution. On the one hand, higher costs (e.g., installation of pollution-reduction devices) incurred to control pollution will negatively affect a firm's industrial activities (Telle, 2006). Because

[12] It was replaced by the Ministry of Environmental Protection of China during the March 2008 National People's Congress sessions in Beijing.
[13] China Environment Statistics Year Book, 1992–2007, Ministry of Environmental Protection, China. Environmental Science Press, Beijing.
[14] See "Water control in China: Review of laws, regulations and policies and their implementation" by the Economic Analysis Team, Institute for Global Environmental Strategies (IGES), April 17, 2009.

additional spending on pollution reduction could eventually harm the firm's profitability and comparative advantage, firms should have few incentives to pursue the CSR on environmental protection (Friedman, 1970). On the other hand, albeit costly, controlling pollution may benefit the firm through enhancing its reputation to attract more investors and/or customers, eventually making the firm more profitable (Oberndorfer et al., 2013). Such reputation gains could be particularly high for public-listed companies that are subject to the scrutiny of public investors. Previous evidence suggests that industrial accidents with environmental consequences are associated with a significant drop in stock market returns.[15] Capelle-Blancard and Laguna (2010) show that the market loss associated with one plant accident such as the explosion in chemical plants can be between $164 million to $1.82 billion U.S. dollars. They also find that the stock market loss is more severe for firms with poor environmental and safety records. Using data from the Korean market, Dasgupta (2000) also find stock market penalties for environmental violations and point out that such penalties are higher in developing countries than those in developed countries. Therefore, we hypothesize that public-listed firms may have stronger incentives to control pollution because the reputation gains from an environmental-friendly image may well exceed the pollution-reduction costs. We form the following hypothesis:

Hypothesis 1b. Other things being equal, public-listed companies has lower pollution intensity than (unlisted) SOEs.

The second major determinant of pollution examined in the paper is local government protection. One notable feature of China's economic reforms over the past three decades is the transition from a highly centralized fiscal system to a gradually decentralized system. As the fiscal decentralization allows local governments to keep part of the tax revenue, it gives local governments strong incentives to maintain the local tax base by protecting local firms against foreign and/or interregional competitions (Ping, 1996; Bai et al., 2004). In addition, pollution by local industries is also tolerated by local governments,[16] who rely on these industries to contribute tax, create job opportunities, promote economic growth and maintain social stabilities (Bai et al., 2004). In fact, local protectionism is deeply rooted because many polluting industries have strong ties with local governments. Sometimes, even government officials themselves (or their family) are owner (or co-owner) of the polluting plants. Anecdotal evidence suggests that many environmental pollution cases can be attributed to the abuse of power by local government officials who blatantly allow pollution to be produced.[17] Naturally, we expect that stronger local protection will lead to more pollution from local firms:

Hypothesis 2. Other things being equal, local protectionism is positively associated with the intensity of pollution emissions.

The third factor that could influence industrial pollution is the strength of law enforcement. In China, environmental officials have little power over bureaucracy: Firms in violation of environmental protection laws do not receive due punishment due to the political connections and local protection we discussed earlier. According to the Coasian hypothesis, good property right protection can reduce or even eliminate externalities, such as pollution. A well-defined and enforced legal system enables individuals to sue the polluting parties effectively. Ajuzie and Altobello (1997) argue that the assignment of property rights leads to efficient resource allocation, increases productivity, and promotes environmental quality. The high variations in the effectiveness of the court system across Chinese cities, as reflected in the 2006 World Bank survey, enable us to explore such relationship. We summarize the above discussion with the following hypothesis:

Hypothesis 3. Other things being equal, better property rights protection is negatively associated with the intensity of firm pollution emissions.

Next we hypothesize that pollution is affected by a firm's exporting activities and its size. Melitz (2003) incorporates firm productivity heterogeneity into the Krugman (1979) monopolistic competition framework, which brought an extensive trade literature to study the influence of firm heterogeneity on trade behavior. In this dynamic industry model, firms choose to export when their productivity exceeds a certain threshold that enables them to generate enough profits to cover the exporting costs. Empirical studies have largely supported the view that exporters tend to be larger and more productive than their competitors in domestic markets. Furthermore, a firm's heterogeneity in production has been shown to affect its pollution emission intensity. Cole et al. (2005) find that emissions are positively correlated with capital intensity and negatively correlated with firm size and productivity. Holladay (2010) shows that exporters are larger than non-exporters due to their productivity advantage; they also generate significantly fewer and less toxic pollution than non-exporters in the same industry do. Moreover, since small-sized firms face more financial constraint to adopt new technologies or update their old machines, to compete with large firms and make a profit, they may maintain dirty and outdated technologies to save costs. The lack of technological flexibility will seriously affect the effective and efficient use of energy and thus lead to more intensive pollution. Together with the above discussion, we expect that the intensity of pollution emissions is negatively associated with firm export and firm size.

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[15] For a summary, please see Capelle-Blancard and Laguna (2010).

[16] Even when local governments regulate polluting plants, they often lower the environmental standards towards local firms that they intend to protect.

[17] Deputy Director of the State Environment Protection Administration (now the Ministry of Environment Protection), PAN Yue, stated that "The governments' refusal or failure to fulfill environmental responsibilities has seriously set back China's environmental protection efforts" (Xinhua News Agency, February 27, 2007, *SPEA: Pollution Control Requires Accountability*).

In addition, pollution intensity is also likely to depend on the education level of local residents. People with more education are more likely to be concerned with their living standards, including the quality of their drinking water and air. They are not only expected to be more aware of the harmful effects of pollution, but also expected to obtain greater welfare surplus by taking responsibility for environmental protection to improve ambient air and water quality. As Weersink and Raymond (2007) document, people with a higher education level tend to be more informative and capable of appealing through formal institutional channels when their interests are potentially harmed by pollution. We use the employees' education level as a proxy for the surrounding residence education level since they tend to live near the polluting plant. Besides, many manufacturing firms are very passive in carrying out environmental protection schemes, partly because of their profit-maximization-driven goals, and partly because of their own employees' ignorance of its importance. We therefore expect that firms with more educated employees will pollute less than their competitors, all other things being equal.

Finally, we argue that pollution may be associated with competition. Market competition may affect a firm's incentive to reduce pollution. In a more competitive market, firms are forced to cut costs and thus are more likely to adopt dirty technology. Moreover, the firm may not have enough resources to adopt cleaner technology due to its lower level of profits as a result of fierce competition. In contrast, competition in the product and labor markets may crowd out the inefficient firms as competition could reduce the output of the least efficient firms. Therefore, the overall effect of competition on pollution is ambiguous.

4. Data and sample selection

4.1. Data sources

The data used in this study are compiled from five sources: (1) the Pollution Data from the Ministry of Environment Protection (MEP, 2006, 2007) of China; (2) the Industry Enterprise Dataset from the National Bureau of Statistics of China (2006, 2007); (3) the World Bank Survey on Governance and Investment Climate Index in 120 Cities in China (2006); (4) the NERI (National Economic Research Institute) Index of Marketization of China's Provinces 2006 Report; and (5) the 2005 Economic Census in China.

The pollution dataset is provided by China's MEP covering a nationwide number of 2862 firms for 2006 and 4261 firms for 2007 (with 2486 firms in both years), from SIC 4-digit manufacturing industries.[18] This database covers all provinces, with plants considered as more important enterprises that are under direct monitoring of the MEP. Even though the database is only a sample of the universe of Chinese firms, an examination of the plants distribution shows that the spatial distribution of plants in this database roughly matches with the general pattern of industrial development in China.[19] Given the importance of the firms being examined, this database is the one that probably has the best coverage and contains the most comprehensive and detailed information of Chinese manufacturing pollution among relevant studies.

In practice, the MEP requires that the manufacturing plants self-report their emissions, but it will conduct monitoring and surprise inspections. False reporting will be penalized upon detection. During the survey, each manufacturing plant files an emission form to provide its last year's pollutant discharge information. This emission form is very detailed and asks for the following: (1) basic information about the plant (including detailed plant address, contact information, number of employees in the environmental protection sector, year of establishment, number of production days for the previous year, total number of employees by the end of the previous year, plant scale, subordination of organization, ownership type, industry category, and value of gross output); (2) the value and capacity of the pollutant disposal equipment and the related expenditure and amount (at both aggregate and separate levels for each pollutant); (3) the volume of water used for production, volume of waste water discharge, and waste water pollutant concentrations (including chemical oxygen demand and ammonia nitrogen); (4) the volume of waste gas discharge and air pollutant concentrations (including sulfur dioxide, burned dust, and industrial soot) in the waste gas; (5) the weight of solid waste discharge; (6) ambient noise pollution; (7) discharge levels over the national quota for each pollutant; (8) total pollution fees paid in the previous year; (9) diagrams of production process; and (10) emission time.

It should be noted that this pollution dataset is collected at the manufacturing plant level. In other words, each firm in the dataset represents one manufacturing plant in one city with detailed plant-level emission data applied to that city.[20] In addition, the dataset contains extensive pollutant emissions information ranging from waste water and air pollution to noise. In this study we mainly focus on three pollutants: sulfur dioxide, waste water, and soot, for three reasons: (1) they are considered the most threatening environmental pollution generated by China's manufacturing sector; (2) they have been used as major indicators to measure environmental pollution in many countries; and (3) the information provided for these three pollutants is

[18] The original database contains 5416 firms for 2006 and 6100 firms for 2007 (with 3634 firms in both years). But as our study requires each plant has at least one of the three types of pollutants emission information (i.e. sulfur dioxide, waste water, and soot), we start with a smaller sample.

[19] In Appendix Fig. A1, we show that the share of the number of firms in each province in our pollution database is highly correlated with the share of the industrial GDP for each province.

[20] Because each firm may include multiple plants and these plants may not be independent of each other, studying plant-level emissions may overstate the statistical significance. However, we carefully checked the data we used and did not find any instance of multiple plants belonging to one firm in our sample. Therefore, our data should be free of this measurement problem.

Table 1
Distribution of pollutant discharges by province.

Province/municipality Unit	Average SO_2 SO_2 (ton)/sales (100 million RMB)	Average wastewater Wastewater (ton)/sales (10,000 RMB)	Average soot Soot (ton)/sales (100 million RMB)
Beijing[a]	26.49	0.00	3.20
Tianjin[a]	27.90	0.06	10.79
Hebei	30.87	2.76	16.15
Shanxi	25.15	0.23	22.12
Neimenggu	48.53	0.04	24.14
Liaoning	47.25	0.08	25.64
Jilin	56.63	0.85	17.15
Heilongjiang	16.59	0.19	21.62
Shanghai[a]	20.44	0.05	1.89
Jiangsu	20.71	1.37	7.79
Zhejiang	20.42	1.23	4.33
Anhui	39.76	1.41	31.23
Fujian	51.75	1.84	16.59
Jiangxi	59.06	4.66	19.26
Shandong	41.74	0.13	25.00
Henan	79.51	6.97	39.93
Hubei	37.09	5.22	20.11
Hunan	51.11	1.85	105.77
Guangdong	16.82	2.75	4.95
Guangxi	68.36	1.99	23.21
Chongqing[a]	120.39	2.68	15.55
Sichuan	70.69	3.72	28.56
Guizhou	120.59	2.10	12.28
Yunnan	16.82	0.27	21.70
Shaanxi	57.97	8.49	29.91
Gansu	32.27	0.14	64.89
Qinghai	53.45	0.10	0.75
Ningxia	46.25	14.76	64.46
Xinjiang	83.45	0.83	114.36
Number of firms	2297	1931	1967

[a] China's municipality directly governed by the central government.

much more complete than that for other pollutant types in the dataset. To check whether our results are sensitive to the choice of pollutants, we also study other indicators such as oxynitride, chemical oxygen demand, and ammonia nitrogen in Section 6.1.

To obtain more firm- and city-level characteristics, we use the plant's name (in Chinese) and its location to link the pollution dataset to the Industry Enterprise Dataset and the World Bank survey databases by hand.[21] The Industry Enterprise Dataset (2006, 2007), covering firms with annual sales over five million RMB from all manufacturing sectors, was compiled by the National Bureau of Statistics of China. It collected almost all important aspects of a firm's operation. We use a subset of this database that includes only manufacturing firms in our MEP dataset. The detailed firm-level information includes ownership types, industry classification, city code, date of establishment, total assets, sales, employee education, outputs, inputs, taxes, and profits, etc.[22] The World Bank survey, conducted in 2006, contains information about the degree of property right protection, the effectiveness of the court of law, and the enterprise tax burden relief index in 120 cities in China, among other things.[23] The measurement for local protection is obtained from the 2006 NERI Marketization Index of China's Provinces. Finally, we collect city-level macroeconomic variables from the Economic Census of China (2005).[24]

After matching the five datasets we obtain a sample of 2842 firm observations (or 1882 firms) across two years that covers 116 cities in China. Out of the 1882 firms, there are 683 (551, 566) firms contain two years of sulfur dioxide (waste water, soot) discharge data.[25] For each firm, we have information on firm characteristics such as pollutant discharge levels, ownership types, firm size, firm age, industry code, R&D expenditure, and leverage in addition to city-level variables such as GDP per capita, unemployment rate, population intensity, and property-right protection. The variable definitions are presented in the Appendix Table A1.

[21] We manually match the pollution dataset and the Industry Enterprise Dataset based on firm names and location in both databases. The World Bank Survey on Governance and Investment Climate Index in 120 Cities in China (2006) contains only city-level information, so this dataset is merged with the pollution dataset based on each firm's city location. Finally, the NERI (National Economic Research Institute) Index of Marketization of China's Provinces 2006 Report contains province-level information, so this database is merged with the pollution dataset based on each firm's province location.

[22] The Industry Enterprise Dataset is lack of firm R&D information. We match firm R&D data using the First Economic Census conducted in 2005 on firm operations in 2004.

[23] The 120 cities cover all of the provinces in mainland China except Tibet. The capital city from each province is included. The inclusion of additional cities for each province depends on the provincial GDP. The 120 cities included in this survey account for 70–80% of China's GDP.

[24] We have done a very careful job by merging different datasets together while they have different (but close) timing of data sources, but we acknowledge that there might still be concerns on data measurement issues given data limitation.

[25] Our merging process requires that each firm has at least one pollutant emission information for one year.

Table 2
Summary statistics.

Variable	Obs.	Mean	Std. dev.	Min	Max
Pollutants					
SO2	2297	51.79	132.28	0	1610.35
SO2_over	2297	6.88	65.77	0	1610.35
Wastewater	1931	3.32	17.72	0	320.72
Wastewater_over	1931	1.72	11.01	0	247.58
Soot	1967	36.26	171.27	0	3893.66
Soot_over	1967	10.64	79.71	0	1239.09
Oxynitride	1576	25.62	38.30	0	289.84
COD	1981	35.37	126.26	0	1781.07
Ammonia nitrogen	1136	2.60	11.58	0	257.37
Ownership					
SOE	2842	0.14	0.34	0	1
Foreign	2842	0.19	0.39	0	1
Private	2842	0.25	0.43	0	1
Public	2842	0.11	0.31	0	1
Collectives	2842	0.05	0.23	0	1
Limited	2842	0.26	0.44	0	1
Firm-level variables					
Export	2842	0.08	0.20	0	1
Firm_size	2842	6.41	1.24	0	11.64
Firm_age	2842	2.69	0.72	1.61	4.97
ROA	2842	0.01	0.02	-0.16	0.28
Leverage	2842	0.59	1.81	0	27.17
R&D	2842	0.00	0.01	0	0.15
Education	2842	0.16	0.16	0	1
Other variables					
Competition	2842	0.03	0.06	0.00	0.58
Local_protection	2842	2.52	1.38	0.76	9.51
Property_right	2842	0.65	0.17	0.27	0.98
Pop_intensity	2842	0.05	0.03	0.01	0.24
Unemployment	2842	0.03	0.01	0.01	0.09
Gdp_per_capita	2842	2.97	1.90	0.47	9.19
Gdp_per_capita2	2842	12.42	16.26	0.22	84.48

Note: All of the variables are defined in Appendix Table A1.

4.2. The intensity of pollutant discharge

The intensity of pollutant discharge, our dependent variable, is calculated as the logarithm of the physical units of a given pollutant of a firm scaled by its annual sales. Table 1 presents the variation distribution of all three pollutant discharges across provinces. We find that coastal provinces have less air pollution on average than the non-coastal provinces but more wastewater pollution than non-coastal provinces.

Next, we briefly discuss how some of our key variables are defined. Out of the 2842 firms in our sample, 2297 reported sulfur dioxide discharges, 1931 reported waste water discharges, and 1967 reported soot discharges. A total of 1473 firms report discharge information for all three pollutants. As the summary statistics in Table 2 show, the intensity of sulfur dioxide discharge in our sample ranges from 0 to 1610.35 tons per RMB100 million in sales (US$1 equals RMB6.5, approximately), with a mean of 51.79.[26] The intensity for waste water discharge ranges from 0 to 320.72 tons per RMB10,000 in sales, with a mean of 3.32. The intensity for soot discharge ranges from 0 to 3893.66 tons per RMB100 million in sales, with a mean of 36.26. Given that the median annual sales of the firms in our sample is RMB2.06 billion. Each year a median-sized firm will discharge about 1067 tons of sulfur dioxide or 747 tons of soot into the air or 684,000 tons of waste water into the river or sea.[27]

A further examination of the sample reveals an uneven distribution of pollutant discharge across both areas and industries. Appendix Fig. A2 shows the average of sulfur dioxide discharge for the 116 cities based on the 2297 firm reports in our sample, as highlighted by circles. The larger the circle is, the more sulfur dioxide pollution from that city. The figure clearly shows that inland cities are suffering more from sulfur dioxide pollution than coastal cities in China. This result is consistent with our findings in Table 1. We further study the variation distribution of pollution across industries. As Fig. 1 shows, the

[26] In China, the levels of sulfur dioxide and soot pollution are measured in two kinds of units: the ambient concentration (mg/m^3) or the mass emission (ton). The mg/m^3 unit measures the concentration of air pollution from all possible sources rather than only manufacturing firms. To accurately measure the industry pollution, the MEP dataset used the mass emission (ton).

[27] According to the MEP's data, China was the largest sulfur dioxide discharge country in the world in 2005 with a total of 25.49 million tons of sulfur dioxide discharge.

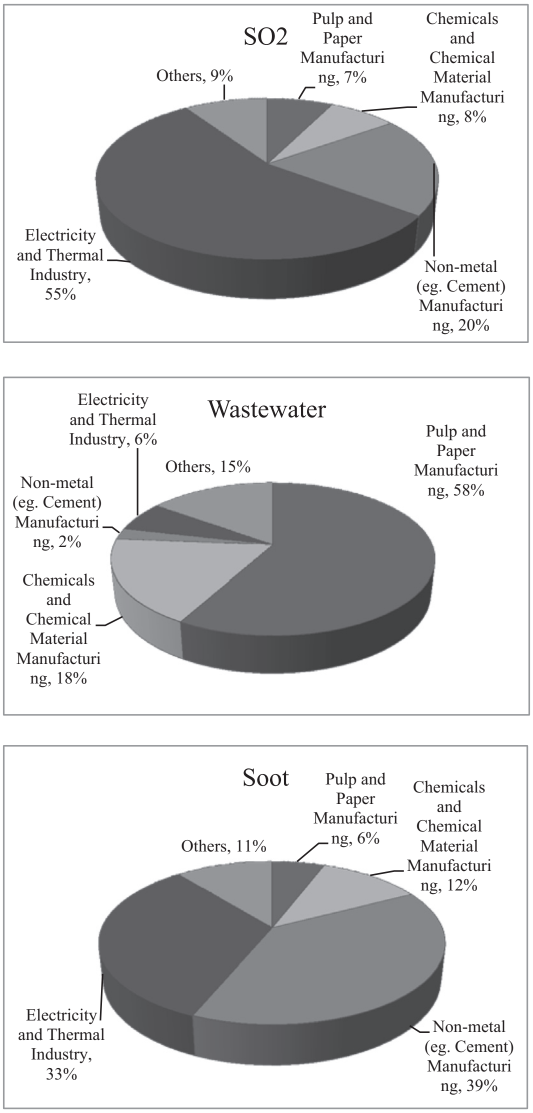

Fig. 1. The distribution of pollutants discharge by industry.

four most heavily polluted industries are pulp and paper manufacturing, chemicals and chemical material manufacturing, non-metal (e.g., cement) manufacturing, and electricity and thermal production. Combined, these four industries contribute to over 85% of the total pollution emissions in the sample, but they only account for 27.72% of the total sales of the sampled firms.

4.3. Other variables

The Industry Census database defines six types of firm ownership: state-owned enterprises (*SOE*), foreign-owned enterprises (*foreign*), privately owned enterprises (*private*), public-listed companies (*public*), collectives (*collectives*), and non-state-owned limited companies (*limited*). These six types of ownership are mutually exclusive. SOEs include various types of SOES: domestic, alliances and unlisted SOEs. Foreign-owned enterprises include enterprises partially or wholly owned by Hong Kong, Macau, Taiwan (HMT) and other foreign investors. Public-listed companies are domestic public-listed companies. Collectives include companies that are registered as collective firms or alliances. As Table 2 reveals, 14% of the firms in our sample are SOEs, 19% are foreign-owned firms, 25% are privately owned firms, 11% are public-listed firms, 5% are collectives, and 26% are domestic non-state-owned limited firms.

Besides the series of ownership indicators, we include two key explanatory variables in our analysis: local protection and property right protection indices. To shield local enterprises from fierce competition with other cities or foreign countries, local governments may create a barrier to support local firms such that new entrants find it very difficult to enter the market

Table 3
Correlation matrices.

Panel A. Correlations between pollutant discharges and firm-level variables

	SO2	Wastewater	Soot	Foreign	Private	Public	Collectives	Limited	Export	Firm_size	Firm_age	ROA	Leverage	R&D
Wastewater	0.1076*													
Soot	0.2146*	0.1430*												
Foreign	−0.0417	−0.0604*	−0.0638*											
Private	−0.064	0.0667*	0.0249	−0.2685*										
Public	−0.0504	−0.0489	−0.0202	−0.1700*	−0.1969*									
Collectives	−0.0068	0.0728*	0.0051	−0.1144*	−0.1325*	−0.0839								
Limited	0.0111	0.0376	0.0468*	−0.2877*	−0.3332*	−0.2110*	−0.1419*							
Export	−0.1128	−0.0490*	−0.0657*	0.2246*	−0.0685*	0.0067	−0.0445*	−0.0737						
Firm_size	−0.0873	−0.1562*	−0.0776*	−0.0224	−0.2750*	0.1743*	−0.1169*	−0.0277	0.1173*					
Firm_age	0.0224	−0.0377	−0.0193	−0.1545*	−0.2230*	0.0903*	0.0620*	−0.0632*	0.0095	0.3474*				
ROA	0.0055	0.0251	0.0127	−0.0216	0.0285	−0.0127	0.0173	0.0079	−0.0216	0.0084	−0.0173			
Leverage	0.0223	0.0136	−0.0002	−0.0345	0.0158	−0.0161	0.0074	0.0183	−0.0405*	−0.0255	−0.0274	−0.0612		
R&D	−0.0475	−0.0438	−0.0058	−0.0103	−0.0452*	0.1093*	−0.0371*	−0.0313	0.1331*	0.1703*	0.1023*	0.0167	−0.025	
Education	0.1428*	−0.0981*	−0.0156	0.1670*	−0.2669*	0.0662*	−0.1531*	−0.0122	−0.012	0.1529*	0.0451*	−0.007	0.0941*	0.1255*

Panel B. Correlations between pollutant discharges and other variables

	SO2	Wastewater	Soot	Competition	Local_protection	Property_right	Pop_intensity	Unemployment	Gdp_per_capita
Wastewater	0.1076*								
Soot	0.2146*	0.1430*							
Competition	−0.0987*	0.0662*	−0.0600*						
Local_protection	0.1055*	0.0957*	0.0869*	0.0085					
Property_right	−0.0225	−0.0321	−0.0683*	−0.0107	−0.4241*				
Pop_intensity	−0.0277	−0.0435*	−0.0112	0.0194	−0.3451*	0.0507*			
Unemployment	0.0276	0.0591*	0.0317	−0.0119	0.2267*	−0.2599*	−0.1959*		
Gdp_per_capita	−0.0992*	−0.0924*	−0.0708*	0.0175	−0.4364*	0.1981*	0.4525*	−0.3298*	
Gdp_per_capita2	−0.0877*	−0.0665*	−0.0607*	0.0170	−0.3826*	0.1700*	0.4171*	−0.3009*	0.9606*

* 5% significance level.

with profitability. Local regulations may also be implemented with extra conditions to limit new entrants. China's auto market is a good example. In 2000, the Shanghai government set a levy of RMB80,000 license fee for each Fukang automobile registered in Shanghai to prevent an increasing market share gained by the Citroen joint venture based in Hubei province. In contrast, the similar Santana model made by the Shanghai Volkswagen company only requires a RMB20,000 license fee. In another example also in Shanghai, the government adopts environmental regulations that are tailored to the technical specifications of locally produced cars, which have effectively prevented other car producers from entering into the market (Bai et al., 2004).[28] We therefore use entry barrier as a proxy for local protectionism in each city in China. The data comes from the NERI Index of Marketization of China's Provinces 2006 Report which measures the efforts exerted by local government to reduce local protectionism in product markets, particularly in the form of abolishing entry barriers to the local market. This report contains year 2003 to 2005 indexes at the province level. We use the year 2003 index in order to avoid the reverse causality problem. However, we do not find our basic results are changed by using year 2004 or 2005 index or the average of the three years data since the within province variation is small during the time span. The 2003 local protection index ranges from 0.76 (Guangdong) to 9.51 (Qinghai), has a mean (median) of 2.52 (2.29), and a standard deviation of 1.38, with a higher value indicating increased entry barriers or more local protection.

The property right protection index is derived from the World Bank Survey on Governance and Investment Climate Index in 120 cities in China (2006). In particular, the survey asks firms to answer the following question, "Among the commercial or other disputes that your company has been involved with, what has been the likelihood (in terms of percentage) that your company's contractual and property rights (including enforcement) are protected?" This index is formed at the city level, ranging from 0.27 (Huhehaote) to 0.98 (Hangzhou), a mean (median) of 0.65 (0.67) and a standard deviation of 0.17, with a higher value representing a perception of better protection of property rights (due to better law enforcement, for example).

We also include a set of other firm-level variables that may affect pollutant discharge. These variables include *export* (the ratio of annual exports value to annual sales), *education*, (the percentage of employees with college and above-college degrees), firm profitability (return on assets or *ROA*), firm size, firm age, leverage, R&D expenses (*R&D*), and industry dummy variables.

Finally, to control for some of the common features that may be shared among local firms, we further include a series of industry- and city-level variables. The industry-level variables include the *competition* variable, measured with the Herfindahl–Hirschman Index (HHI) as the sum of the squared market shares of all of the firms in the industry at the 4-digit SIC level. The HHI index is computed from the National Bureau of Statistics (NSB) Enterprise Database with the lower limit of zero representing perfect competition and the upper limit of 1 representing monopoly. In our sample, this index ranges from 0.00 to 0.58.

To ensure that the pollutant discharge intensities of each firm are driven by the key explanatory variables and not others, we further include a series of city-level control variables: population intensity (*pop_intensity*), unemployment rate (*unemployment*), GDP per capita (*GDP_per_capita*), and GDP per capita square (*GDP_per_capita2*). These variables measure the overall level of economic development.

5. Empirical results

5.1. Univariate analysis

The correlation matrix between pollutant discharge and firm-level variables is shown in Panel A of Table 3. We determine the following: (i) the intensities of all pollutant discharges are positively correlated with one another; (ii) foreign-owned firms and domestic public-listed firms have a lower intensity of all pollutant discharges than SOEs; (iii) export is negatively correlated with pollution; (iv) bigger firms pollute less than smaller firms; and (v) the higher employees' education levels are, the lower their firm's pollutant intensities.

The correlation matrix between pollutant discharges and other variables is shown in Panel B of Table 3. We do not find consistent correlation between competition and pollution. However, we do find evidence of the following: (1) the intensity of pollutant discharge is positively correlated with local protection and negatively correlated with property right protection; (2) cities with less population density suffer from more pollution; (3) cities with higher unemployment rates are associated with increased industrial pollution; and (4) people in cities with higher GDP per capita suffer less from pollution. Next, we conduct a multivariate analysis.

5.2. Basic regression: determinants of pollution intensity

To examine the determinants of pollution intensity, we assume that the firm-level intensity of pollutant discharge is a function of firm ownership, firm-level characteristics, city-level characteristics, property-right protection, competition, industry fixed effects, year fixed effects, and an unobserved error term.

We employ a pooled ordinary least squares (OLS) model to estimate the intensity of sulfur dioxide, waste water, and soot, respectively, as opposed to a fixed effects model because ownership does not change over time. The main OLS regression

[28] Regional Protectionism Weakening State Capacity 3/27/2011, extracted from: http://china.org.cn/english/2001/Mar/9673.htm.

Table 4
Determinants of pollutants discharge: OLS regression.

Variables	(1) SO2	(2) Water	(3) Soot	(4) SO2	(5) Water	(6) Soot
Foreign	−0.4952***	−1.0310***	−0.4731**	−0.4481***	−0.9203***	−0.3737*
	(0.1574)	(0.2667)	(0.2110)	(0.1550)	(0.2585)	(0.2070)
Private	−0.1581	−0.4232	0.1535	−0.1307	−0.3443	0.2166
	(0.1893)	(0.3062)	(0.2391)	(0.1865)	(0.3020)	(0.2357)
Public	−0.5008***	−0.7950***	−0.3217	−0.4814***	−0.7417***	−0.2611
	(0.1769)	(0.2450)	(0.2017)	(0.1798)	(0.2413)	(0.2064)
Collectives	0.0410	−0.6510**	0.1375	0.0622	−0.5866*	0.1777
	(0.2055)	(0.3275)	(0.3215)	(0.2035)	(0.3188)	(0.3121)
Limited	−0.3505**	−0.6572**	−0.2168	−0.3185**	−0.5740**	−0.1440
	(0.1445)	(0.2670)	(0.1951)	(0.1419)	(0.2602)	(0.1926)
Export	−0.7513***	−0.8534**	−1.1128***	−0.7600***	−0.8470**	−1.1174***
	(0.2582)	(0.3300)	(0.2881)	(0.2602)	(0.3247)	(0.2893)
Firm_size	−0.1059**	−0.9381***	−0.1520***	−0.1109***	−0.9480***	−0.1639***
	(0.0418)	(0.0856)	(0.0484)	(0.0414)	(0.0860)	(0.0483)
Firm_age	0.0542	0.1801*	−0.1195	0.0674	0.2074**	−0.0914
	(0.0715)	(0.0940)	(0.0914)	(0.0710)	(0.0925)	(0.0892)
ROA	2.2196	−10.3034**	−0.5286	2.3136	−10.2500**	−0.0267
	(3.4132)	(4.6707)	(3.2610)	(3.3916)	(4.6894)	(3.2567)
Leverage	0.0163	0.0515**	0.0171	0.0156	0.0516**	0.0185
	(0.0155)	(0.0246)	(0.0151)	(0.0156)	(0.0247)	(0.0154)
R&D	−8.8802	−1.8945	−10.7060**	−8.9838	−1.2521	−10.0911*
	(7.8632)	(6.6989)	(5.3157)	(7.7240)	(6.5579)	(5.1114)
Education	−0.9712**	−3.7288***	−1.5565***	−0.9922**	−3.8268***	−1.6260***
	(0.3886)	(0.5778)	(0.3661)	(0.3855)	(0.5834)	(0.3652)
Competition	−0.1453	−1.7989*	−1.0408	−0.0395	−1.6363	−0.8357
	(0.9979)	(1.0644)	(1.2423)	(1.0087)	(1.0443)	(1.2814)
Local_protection				0.0701	0.1271**	0.1123**
				(0.0455)	(0.0520)	(0.0546)
Property_right				0.0457	−0.2453	−0.4515
				(0.3543)	(0.4247)	(0.4179)
Pop_intensity	−2.7949	−6.0860***	−7.0009***	−2.8750	−6.8670***	−7.6003***
	(1.9843)	(2.2349)	(2.0585)	(2.0476)	(2.2171)	(2.2658)
Unemployment	−2.4824	−2.8643	−2.9797	−3.0982	−5.5566	−5.3664
	(3.4280)	(5.2585)	(4.2244)	(3.7137)	(5.3151)	(4.4212)
Gdp_per_capita	−0.1100	−0.6681***	−0.4296***	−0.0724	−0.5971***	−0.3512**
	(0.1067)	(0.1146)	(0.1371)	(0.1120)	(0.1196)	(0.1392)
Gdp_per_capita2	−0.0008	0.0589***	0.0318**	−0.0034	0.0546***	0.0267*
	(0.0123)	(0.0112)	(0.0148)	(0.0125)	(0.0113)	(0.0157)
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2297	1931	1967	2297	1931	1967
R-squared	0.4060	0.6052	0.3899	0.4077	0.6079	0.3959

Columns (1)–(3) show the OLS regressions with the logarithm of the amount of SO_2, waste water and soot discharge as the dependent variable, respectively. Columns (4)–(6) add two more variables (*local_protection* and *property_right*) into the regressions by using the same respective dependent variable as in (1)–(3). Robust standard errors clustered with cities are in brackets.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

results are shown in Table 4. The robust standard errors reported here are corrected for correlation across firms within the same city (i.e. clustered at the city level).

There are several interesting findings. First, the coefficients on foreign-owned firms are negative and statistically different from zero, suggesting that compared to SOEs (the base group), foreign firms discharge less sulfur dioxide, waste water, or soot per unit of sales. Second, in similar magnitude, domestic public-listed firms also have lower pollution intensity than SOEs, suggesting that they take more social responsibility due to the scrutiny of public investors. Third, firms that export more, are larger in size, or have more educated employees are less likely to generate pollutant discharge. Local protection appears to have a statistically significant effect on pollutant discharges (except for sulfur dioxide), although competition and property right protection do not seem to be correlated with pollutant discharges.

The effects of foreign ownership are not only statistically, but also economically significant. We calculate the marginal effect of foreign ownership on pollution discharge intensity using the formula $100[\exp(b - \text{var}(b)/2) - 1]$, where b represents the estimated coefficient and $var(b)$ represents the variance of b.[29] The coefficients on foreign ownership suggest that com-

[29] Please see Halvorsen and Palmquist (1980) and Kennedy (1981) for a discussion about the interpretation of the coefficients of dummy variables when the dependent variable is log-transformed.

Table 5
Pollutants discharge over standard level.

Variables Model	(1) Log(SO2_over) OLS	(2) Log(polluted water_over) OLS	(3) Log(soot_over) OLS	(4) Log(SO2_over) TOBIT	(5) Log(polluted water_over) TOBIT	(6) Log(soot_over) TOBIT
Foreign	−0.2329*	−0.1809**	−0.1574*	−0.2657**	−0.191***	−0.1792
	(0.1359)	(0.0800)	(0.0907)	[0.1240]	[0.0640]	[0.1049]
Private	−0.2007	−0.0399	−0.0137	−0.2994**	−0.0862	−0.1256
	(0.1280)	(0.0947)	(0.1291)	[0.1198]	[0.0659]	[0.1037]
Public	−0.2185*	−0.1657	−0.1077	−0.2300*	−0.1142*	−0.1399
	(0.1228)	(0.1058)	(0.1084)	[0.1258]	[0.0626]	[0.1119]
Collectives	−0.1349	−0.4547***	−0.0598	−0.2555	−0.3285***	−0.2334*
	(0.2001)	(0.1266)	(0.2521)	[0.1457]	[0.0709]	[0.1264]
Limited	−0.1981	−0.1531*	−0.0707	−0.2284**	−0.1716***	−0.1247
	(0.1256)	(0.0819)	(0.0932)	[0.1119]	[0.0586]	[0.0943]
Export	−0.1385	0.0330	−0.1715	−0.0616	0.133	−0.1316
	(0.1080)	(0.0985)	(0.1158)	[0.2054]	[0.0849]	[0.1638]
Firm_size	−0.0983***	−0.0544*	−0.1248***	−0.1632***	−0.041**	−0.1346***
	(0.0319)	(0.0276)	(0.0387)	[0.0376]	[0.0177]	[0.0298]
Firm_age	0.0195	−0.0276	−0.0552	0.0321	−0.0237	−0.0422
	(0.0454)	(0.0352)	(0.0716)	[0.0518]	[0.0272]	[0.0435]
ROA	1.0291	0.7637	1.0397	1.9823	1.0484	1.2309
	(1.5182)	(1.5422)	(1.9279)	[2.0284]	[0.9663]	[1.6630]
Leverage	−0.0143	−0.0376***	−0.0125	−0.0195	−0.0517***	−0.0182
	(0.0109)	(0.0108)	(0.0172)	[0.0226]	[0.0181]	[0.0158]
R&D	−0.7955	1.7317	−0.7845	−0.7944	1.1319	−1.7359
	(2.1081)	(3.0104)	(2.7129)	[5.5196]	[2.3137]	[4.7495]
Education	−0.0616	−0.2045	−0.3282	−0.0749	−0.0593	−0.2752
	(0.1798)	(0.2146)	(0.2143)	[0.2609]	[0.1459]	[0.2089]
Competition	−0.0768	0.1468	0.5252	−0.1147	0.0931	0.4277
	(0.4971)	(0.4263)	(0.5357)	[0.7529]	[0.3341]	[0.5812]
Local_protection	0.0020	0.0587	0.0637	−0.0259	0.0108	0.0377
	(0.0334)	(0.0494)	(0.0466)	[0.0287]	[0.0145]	[0.0231]
Property_right	−0.9124*	−0.6685**	−1.2912**	−1.2049***	−0.6303***	−1.1867***
	(0.4733)	(0.3087)	(0.6029)	[0.2241]	[0.1080]	[0.1841]
Pop_intensity	−0.7549	−1.4090	−2.0175	−0.6552	−0.2009	−1.5633
	(1.3602)	(1.2170)	(1.6943)	[1.4040]	[0.5925]	[1.1122]
Unemployment	−1.3089	1.0441	−3.2607	−0.9386	3.0644**	−2.905
	(2.7061)	(2.8182)	(3.5341)	[2.6127]	[1.3597]	[2.1556]
Gdp_per_capita	−0.1225	−0.1139*	−0.1342	−0.1159	−0.0473	−0.1435**
	(0.0743)	(0.0667)	(0.0928)	[0.0815]	[0.0350]	[0.0621]
Gdp_per_capita2	0.0089	0.0116	0.0125	0.0002	0.0049	0.009
	(0.0073)	(0.0070)	(0.0095)	[0.0104]	[0.0038]	[0.0076]
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2297	1931	1967	2297	1931	1967
R-squared	0.0634	0.1393	0.1645	0.0740	0.0832	0.1270

Note: Columns (1)–(3) show the OLS estimates with the logarithm of the intensity of sulfur dioxide, wastewater and soot over-discharge as the dependent variable, respectively. Columns (4)–(6) show the marginal effects for the Tobit model by repeating the same estimation as above. The inverse hyperbolic sine transformation of above-quota emission is used as the dependent variable to avoid the log(0) problem. All of the variables are defined in Appendix Table A1. Robust standard errors clustered with cities are in brackets.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

pared to SOEs, foreign firms will discharge less sulfur dioxide by 38%, less waste water by 63%, and less soot by 35%. Evaluated at the sample means, these reductions translate into 19.68 tons of sulfur dioxide per RMB100 million in sales, 209 tons of water per RMB10,000 in sales, or 12.69 tons of soot per RMB100 million in sales.

5.3. Determinants of above-quota pollutant discharge

Thus far our analysis has focused on the overall level of pollutant discharge, but what probably threatens the environment more is the part of discharge that goes beyond the quota set by the national emission standards.[30] As the pollution survey data also contain firm-reported above-quota discharge levels,[31] we use the same specification as before to examine to what ex-

[30] See integrated emission standard of air pollutants (GB16297-1996) and integrated wastewater discharge standard (GB8978-1996) in People's Republic of China.
[31] In our sample, 8.45% of firms had sulfur dioxide over-discharge, 19.32% of firms had wastewater over-discharge, and 10.63% of firms had industrial soot over-discharge.

Table 6
Determinants of pollutants discharge: heavy vs. non-heavy polluted industries.

DEPVAR Heavy polluted industry	(1) Log(SO2) Yes	(2) Log(water) Yes	(3) Log(soot) Yes	(4) Log(SO2) No	(5) Log(water) No	(6) Log(soot) No
Foreign	−0.4872***	−0.7733**	−0.4035*	−0.3028	−1.1436***	−0.3115
	(0.1420)	(0.3108)	(0.2183)	(0.3775)	(0.3849)	(0.3879)
Private	−0.2964	0.0254	0.1193	0.1533	−0.8552*	0.3351
	(0.1805)	(0.3305)	(0.2653)	(0.3784)	(0.4834)	(0.3952)
Public	−0.6396***	−0.6450**	−0.3410	−0.1966	−0.8470**	−0.1496
	(0.1919)	(0.2892)	(0.2278)	(0.3171)	(0.3810)	(0.3469)
Collectives	0.0051	−0.0354	0.3659	0.0805	−1.9080***	−0.5275
	(0.1845)	(0.3437)	(0.3688)	(0.4936)	(0.5435)	(0.5110)
Limited	−0.3674**	−0.3529	−0.2224	−0.2784	−0.8960**	−0.0145
	(0.1445)	(0.2934)	(0.2107)	(0.2919)	(0.4018)	(0.3352)
Export	−0.4942	−0.4576	−0.7920*	−0.8491***	−1.0163***	−1.2942***
	(0.4238)	(0.4684)	(0.4344)	(0.3181)	(0.3691)	(0.3437)
firm_size	−0.0744	−0.8352***	−0.1023	−0.1426*	−1.0576***	−0.2431***
	(0.0476)	(0.0820)	(0.0710)	(0.0859)	(0.1307)	(0.0804)
Firm_age	0.1425*	0.1337	−0.0289	−0.0588	0.2983*	−0.1892
	(0.0746)	(0.0989)	(0.1019)	(0.1372)	(0.1705)	(0.1435)
ROA	6.3334	−7.9898	6.0315	−1.6426	−12.6650**	−4.9466
	(3.9564)	(6.4912)	(4.4389)	(4.5990)	(5.1221)	(3.5776)
Leverage	0.0058	0.0437**	0.0237	0.0697*	0.1021	0.0379
	(0.0148)	(0.0213)	(0.0164)	(0.0410)	(0.0798)	(0.0489)
R&D	7.0386	−19.2441	−0.8688	−12.2501	2.6268	−10.9848
	(4.7022)	(18.2892)	(8.8000)	(7.9550)	(8.0106)	(6.8670)
Education	−0.4891	−4.2871***	−1.3818***	−2.1910*	−2.9930***	−2.2663**
	(0.3013)	(0.6320)	(0.3180)	(1.1457)	(1.1106)	(0.9799)
Competition	0.5744	−1.4074	0.2292	−1.5341	1.7307	−3.2951
	(0.8752)	(0.9788)	(0.9139)	(2.0686)	(1.8684)	(2.3572)
Local_protection	0.0588	0.1601***	0.0959	0.0810	0.0001	0.0944
	(0.0500)	(0.0600)	(0.0646)	(0.0868)	(0.0780)	(0.0910)
Property_right	−0.0224	−0.2812	−0.5003	0.0756	0.0542	−0.5111
	(0.3681)	(0.4400)	(0.5151)	(0.6427)	(0.7474)	(0.7520)
Pop_intensity	−0.4295	−8.6012**	−5.2121**	−6.4701**	-4.2771	−11.4061***
	(2.0675)	(3.4081)	(2.5937)	(3.2596)	(3.2685)	(3.4132)
Unemployment	3.1807	6.8870	0.7751	−12.1795*	−20.0631***	−11.4130**
	(4.0128)	(6.1363)	(5.1994)	(6.4177)	(6.9122)	(5.6453)
Gdp_per_capita	−0.1226	−0.6485***	−0.4870***	0.0112	−0.3419*	−0.1091
	(0.0948)	(0.1408)	(0.1379)	(0.2140)	(0.1941)	(0.2229)
Gdp_per_capita2	0.0035	0.0601***	0.0426***	−0.0144	0.0285*	−0.0001
	(0.0093)	(0.0138)	(0.0137)	(0.0236)	(0.0167)	(0.0243)
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1511	1141	1230	786	790	737
R-squared	0.3309	0.5509	0.3021	0.2552	0.6662	0.3268

Columns (1)–(3) show the OLS regression for heavy polluted industries, with the logarithm of the amount of SO_2, waste water and soot discharge as the dependent variable, respectively; Columns (4)–(6) show the OLS regression for non-heavy polluted industries. Heavy industries include (i) pulp and paper manufacturing, (ii) chemicals and chemical material manufacturing, (iii) non-metal (e.g. cement) manufacturing, and (iv) electricity and thermal industry, in our sample. Robust standard errors clustered with cities are in brackets.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

tent those factors affect above-quota pollution levels. In particular, we set emissions for firms at or below the quota at zero. We use the inverse hyperbolic sine transformation of the above-quota emissions as the dependent variable to avoid the log(0) problem.[32]

The OLS estimates for the three pollutants are shown in columns (1)–(3) of Table 5. In general, the effects on above-quota pollution are similar to those on overall pollution levels, although the sign for soot over-discharge is negative but not statistically significant. Columns (4)–(6) repeat the estimates from a Tobit model and again, the estimated effects are consistent with the effects on overall pollution. The marginal effects actually show a larger magnitude on foreign ownership influence with the Tobit model. It is worth noting that although we did not find that property right protection has a consistent significant effect on total pollution levels, regarding pollutant over-discharge we find that a better institution characterized by a

[32] The inverse hyperbolic sine transformation is expressed as the logarithm of (above-quota emission + sqrt (above-quota emission^2 + 1). For more details about the transformation, please see Zhang et al. (2000).

Table 7
Determinants of pollutants discharge: coastal vs. non-coastal areas.

DEPVAR	(1) Log(SO2)	(2) Log(water)	(3) Log(soot)	(4) Log(SO2)	(5) Log(water)	(6) Log(soot)
	Coastal area			Non-coastal area		
Foreign	−0.5273***	−0.8056***	−0.5180***	−0.4029*	−1.0910***	−0.3634
	(0.1708)	(0.2712)	(0.1943)	(0.2180)	(0.3098)	(0.2697)
Private	−0.2712	−0.3287	−0.1202	0.0079	−0.5023	0.4989*
	(0.1862)	(0.2928)	(0.2192)	(0.2136)	(0.3063)	(0.2776)
Public	−0.5987***	−0.4557*	−0.5837***	−0.4398**	−1.1378***	−0.1550
	(0.1993)	(0.2658)	(0.2075)	(0.2137)	(0.2774)	(0.2744)
Collectives	−0.3439	−0.6646*	−0.3883	0.1710	−0.6861*	0.6158*
	(0.2236)	(0.3503)	(0.2585)	(0.2501)	(0.4067)	(0.3455)
Limited	−0.3947**	−0.4435*	−0.4320**	−0.2091	−0.7319***	0.0844
	(0.1568)	(0.2432)	(0.1803)	(0.1926)	(0.2814)	(0.2456)
Export	−0.8541***	−1.2527***	−1.0491***	−0.5758*	−0.1835	−1.3314***
	(0.2717)	(0.2599)	(0.2700)	(0.3408)	(0.5455)	(0.4150)
Firm_size	−0.0825**	−0.8770***	−0.1070**	−0.1727***	−1.0904***	−0.2386***
	(0.0402)	(0.0819)	(0.0457)	(0.0596)	(0.0895)	(0.0770)
Firm_age	0.0619	0.2536***	−0.0068	0.0781	0.0669	−0.2024*
	(0.0654)	(0.0975)	(0.0780)	(0.0799)	(0.1195)	(0.1127)
ROA	−1.9805	−17.5749***	−2.5207	5.8038	−4.6740	−2.2473
	(3.6615)	(5.1348)	(2.9090)	(4.1031)	(5.0510)	(5.6638)
Leverage	0.0263	0.0789***	0.0535***	−0.0010	0.0205	−0.0238
	(0.0179)	(0.0287)	(0.0194)	(0.0160)	(0.0342)	(0.0192)
R&D	11.2745	−9.1317	12.9444	−12.8284**	9.8021	−17.2185***
	(9.5913)	(12.2553)	(12.0499)	(6.1267)	(6.2031)	(4.9506)
Education	−1.1636**	−3.4647***	−2.0578***	−0.9492**	−4.7769***	−1.4733***
	(0.4711)	(0.6109)	(0.4187)	(0.3714)	(0.6301)	(0.4236)
Competition	0.6278	−2.1068*	0.8416	−0.6261	−1.0499	−1.8275
	(0.9786)	(1.1577)	(1.0454)	(1.4694)	(1.3067)	(1.4811)
Local_protection	0.0051	−0.0505	0.1284*	−0.0085	0.0990	0.0481
	(0.0673)	(0.0803)	(0.0762)	(0.0481)	(0.0737)	(0.0676)
Property_right	0.0261	−0.2910	0.0056	−0.2692	−0.5062	−0.1654
	(0.2845)	(0.4420)	(0.3063)	(0.3786)	(0.5138)	(0.4723)
Pop_intensity	−3.9560**	−8.5847***	−2.7475	1.4144	−2.8267	−10.1048***
	(1.7215)	(2.5940)	(1.9756)	(3.0526)	(3.8755)	(3.6024)
Unemployment	5.1589	3.2550	5.0385	−11.2236***	−13.2023**	−10.2529**
	(3.5461)	(5.9222)	(4.2040)	(3.6512)	(5.8816)	(4.6591)
Gdp_per_capita	−0.2409***	−0.6213***	−0.6721***	0.7183***	0.0572	0.7513***
	(0.0869)	(0.1368)	(0.1053)	(0.1840)	(0.2579)	(0.2586)
Gdp_per_capita2	0.0170*	0.0611***	0.0568***	−0.1327***	−0.0621	−0.1208***
	(0.0089)	(0.0132)	(0.0102)	(0.0321)	(0.0413)	(0.0453)
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1322	1172	1171	975	759	796
R-squared	0.4719	0.6223	0.4518	0.3875	0.6275	0.3750

Columns (1)–(3) show the OLS estimates for firms in coastal areas, with the logarithm of the intensity of SO_2, waste water and soot discharge as the dependent variable, respectively. Columns (4)–(6) show the OLS estimates for firms in non-coastal areas. Coastal areas include 11 coastal provinces - Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi, Hainan, Tianjin and Shanghai. Robust standard errors clustered with cities are in brackets.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

good court of law has a significant effect on pollution reduction when the pollution emissions exceed the standard level. This is not surprising because the law comes into effect when firms violate the environmental protection rules. Hence, better law enforcement effectively reduces pollution over-discharges for all three of the pollutant types in our sample.

5.4. Heterogeneous effects by industry and area

Given that the pollution emissions are unevenly concentrated in certain industries or areas, it is also interesting to investigate whether the effects of various determinants of pollution are different across industries or regions.

First, we run the OLS estimation for two separate samples: one including firms from the four most heavy-polluted industries (about 60% of the full sample) and the other including all of the remaining firms. Table 6 reports the regression results (columns (1)–(3) for heavy-polluted industries and columns (4)–(6) for non-heavy-polluted industries). The results suggest several different aspects regarding the pollutant determinants across industries. First, we find that foreign firms have fewer

Table 8
Determinants of pollutants discharge: local protection towards small-sized firms.

DEP VAR	(1) Log(SO2)	(2) Log(SO2)	(3) Log(water)	(4) Log(water)	(5) Log(soot)	(6) Log(soot)
Foreign	−0.4105***	−0.4188***	−0.6507**	−0.6554**	−0.3109	−0.3203
	(0.1536)	(0.1524)	(0.2691)	(0.2677)	(0.2072)	(0.2060)
Private	−0.0817	−0.1015	0.1869	0.1443	0.3065	0.2636
	(0.1804)	(0.1791)	(0.2869)	(0.2831)	(0.2399)	(0.2360)
Public	−0.4691**	−0.4816***	−0.6840**	−0.6967**	−0.2344	−0.2578
	(0.1796)	(0.1771)	(0.2703)	(0.2684)	(0.2067)	(0.2045)
Collectives	0.1032	0.0809	−0.1115	−0.1595	0.2484	0.1880
	(0.2072)	(0.2075)	(0.3024)	(0.3016)	(0.3204)	(0.3193)
Limited	−0.2812**	−0.2983**	−0.3299	−0.3556	−0.0824	−0.1125
	(0.1386)	(0.1375)	(0.2612)	(0.2604)	(0.1932)	(0.1895)
Small	0.2574***	−0.0429	1.3834***	0.7675***	0.3219***	−0.2898
	(0.0901)	(0.1726)	(0.1497)	(0.2814)	(0.1141)	(0.2125)
Local_protection	0.0663	0.0351	0.0994*	0.0508	0.1069*	0.0589
	(0.0451)	(0.0501)	(0.0535)	(0.0522)	(0.0554)	(0.0601)
Local_protection × small		0.1243*		0.2697***		0.2622***
		(0.0679)		(0.0948)		(0.0940)
Export	−0.7652***	−0.7959***	−0.8725**	−0.9123**	−1.1178***	−1.1721***
	(0.2616)	(0.2613)	(0.3866)	(0.3892)	(0.2942)	(0.2933)
Firm_age	0.0469	0.0450	−0.0697	−0.0737	−0.1290	−0.1335
	(0.0711)	(0.0707)	(0.0983)	(0.0985)	(0.0880)	(0.0878)
ROA	2.0770	1.9450	−11.4125**	−11.4917**	−0.4005	−0.6088
	(3.4076)	(3.3418)	(4.8677)	(4.8506)	(3.2415)	(3.1578)
Leverage	0.0150	0.0141	0.0522**	0.0553**	0.0180	0.0156
	(0.0157)	(0.0159)	(0.0248)	(0.0249)	(0.0153)	(0.0154)
R&D	−9.2424	−8.9865	−6.1560	−5.6643	−10.6616**	−10.0978**
	(7.4073)	(7.3503)	(8.9168)	(9.0927)	(5.0210)	(4.9413)
Education	−1.0310***	−1.0551***	−3.9995***	−4.0548***	−1.6739***	−1.7550***
	(0.3867)	(0.3887)	(0.6047)	(0.6066)	(0.3670)	(0.3744)
Competition	−0.0516	−0.0527	−1.8780	−1.8851	−0.8599	−0.8525
	(0.9806)	(0.9708)	(1.2570)	(1.2593)	(1.2381)	(1.2238)
Property_right	0.0309	0.0085	-0.3134	−0.3420	−0.4724	−0.5000
	(0.3524)	(0.3462)	(0.4551)	(0.4584)	(0.4199)	(0.4083)
Pop_intensity	−2.9695	−2.8820	−7.2673***	−7.2220***	−7.7071***	−7.6258***
	(2.0661)	(2.0420)	(2.2799)	(2.3124)	(2.3341)	(2.3396)
Unemployment	-3.4182	−3.5325	−9.9660	−10.5351*	−6.2082	−6.6621
	(3.6863)	(3.6313)	(6.2496)	(6.1522)	(4.3791)	(4.3074)
Gdp_per_capita	−0.0855	−0.0752	−0.7063***	−0.6758***	−0.3792***	−0.3473**
	(0.1116)	(0.1104)	(0.1321)	(0.1365)	(0.1378)	(0.1357)
Gdp_per_capita2	−0.0020	−0.0031	0.0653***	0.0624***	0.0295*	0.0263*
	(0.0124)	(0.0122)	(0.0130)	(0.0134)	(0.0155)	(0.0152)
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2297	2297	1931	1931	1967	1967
R-squared	0.4076	0.4089	0.5550	0.5570	0.3940	0.3980

Columns (1), (3) and (5) show the OLS regressions with the logarithm of the amount of SO_2, waste water and soot discharge as the dependent variable, respectively. These regressions include the firm size dummy variable *small*, which takes the value of one if firm size is within the 25 percentile of small-sized firms, or zero otherwise. Columns (2), (4) and (6) show the same regressions as in (1), (3), and (5), respectively, by including the interaction term between *local_protection* and *small*. Local_protection is a province-level measurement, and a higher value indicates a higher entry barrier, thus more local protection. Robust standard errors clustered with cities are in brackets.

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

pollution emissions compared to SOEs in the heavy-polluted industries. In contrast, the foreign ownership effect is not obvious in the non-heavy-polluted industries, except for the waste water discharge. We conduct a Chow test and the differences in the coefficients of the two samples are statistically significant at the 5% level. Second, we find that larger firms and firms with more educated employees pollute less in both samples. Lastly, it is interesting to note that the estimated coefficients for export are all statistically significant at the 1% level for the non-heavy-polluted industry sample. They are negative but almost not statistically significant in the heavy-polluted industry sample. This suggests that exporting firms pollute less and the effect is more pronounced in non-heavy-polluted industries.

Next, to check whether the main effects also vary by area, we separate the sample by firm location. In particular, we define a firm as "coastal" if it is located in one of the eleven coastal provinces,[33] and "non-coastal" otherwise. The respective OLS estimates for the coastal (columns (1)–(3)) and non-coastal (columns (4)–(6)) samples are reported in Table 7. The regression

[33] The eleven coastal provinces include Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi, Hainan, Tianjin, and Shanghai.

results show a larger magnitude of air pollution reduction and a smaller magnitude of waste water reduction for foreign firms in coastal areas than for those in non-coastal areas. This indicates that the foreign ownership effect is more pronounced on air pollution control but less so on waste water pollution reduction in coastal areas compared to non-coastal areas. The Chow test shows that the differences in the coefficients of the two samples are statistically significant at the 5% level. We also find that larger firms and firms with more educated employees pollute less in both samples.

Interestingly, we find that the coefficients of GDP per capita are positive and the coefficients of GDP per capita square are negative and significant in models for non-coastal areas, indicating a consistent result of an inversed-U shape Kuznets curve and the pollutant discharge increases with GDP per capita at a decreasing rate. The results also indicate that the turning point of the inversed-U curve comes at a level of GDP per capita of about US$3,300 in non-coastal areas, which is much lower than that estimated by Grossman and Krueger (1995).[34] In the coastal areas, however, there is no evidence for the Kuznets curve. We find that the pollutant discharge decreases with GDP per capita at a decreasing rate, which at least suggests that the higher incomes in China's coastal areas have been associated with lower pollution levels.

5.5. Other determinants of pollution intensity: firm size

In China, the Law of Water Pollution Prevention is a legal framework for water protection and water pollution prevention, but local governments still have the flexibility to formulate local laws, rules, regulations, and standards based on local situations. This also applies in relation to air pollution prevention. In our baseline regression, we find that small firms discharge more pollutants on average than large firms. Small firms pollution problems are more likely to be ignored by government officials than those of large-sized firms, and thus it is more common for local governments to indulge small firms, especially those who want to alleviate local employment pressure. Thus, we expect the effect of local protection on environmental pollution to be more serious within small-sized firms. To test this conjecture, we include an interaction term (*local_protection x small*) to capture this additional effect. The results in Table 8 show that the estimated coefficient for the interaction term is not only positive, but also statistically significant. These results suggest that local protectionism toward small firms increase the sulfur dioxide discharge intensity by 12%, waste water discharge intensity by 29%, and soot discharge intensity by 26%, compared to large firms.

6. Specification tests and discussions

So far we have shown that several factors are correlated with firm-level pollution intensity. However, we have to admit that these correlations may not necessarily imply causality because of the following reasons. First, there is a reverse causality possibility that pollution itself may deter foreign investment. Second, some unobserved firm characteristics (such as managerial ability) may both affect a firm's emission trajectory and its attractiveness to foreign investment, leading to omitted variable biases. Similarly, export ratio and firm profitability may also be endogenously determined if they are both correlated with unobserved determinants of productivity. Things like these will weaken identification in the specifications in this study. Despite these limitations, our main results from the OLS regressions are generally consistent with some theoretical predictions and previous empirical studies. Yet to increase the confidence in our estimates, in this section, we perform some additional specification tests and discuss their implications.

6.1. Additional pollutants

We first examine three additional pollutants, namely oxynitride, chemical oxygen demand (COD), and ammonia nitrogen. Although they are also important indicators of air or water pollution, we do not use them in our main regressions due to lots of missing values in them. Table 9 presents the results from OLS regressions using these three pollutants as dependent variables. The estimates generally exhibit a pattern that is similar to that of our main findings, though the sample size substantially decreases. This suggests that the effects of various pollution determinants are not sensitive to the type of pollutants examined.

6.2. Unbalanced data

Though some firms do happen to appear in both of the 2006 and 2007 surveys, our pollution dataset basically pools two cross-sectional samples and is by design not a balanced panel dataset. Moreover, because not all of the firms discharge sulfur dioxide, waste water, and soot at the same time, the sample sizes are different for the regressions with different pollutants as dependent variables. Overall, the original pollution data contains 5904 firm year observations with discharge of sulfur dioxide, 4753 observations with discharge of waste water, and 5253 observations with discharge of soot. Among them, 1726 firms (3524 observations) with discharge of sulfur dioxide, 1473 firms (2946 observations) with discharge of waste water, and 1589 firms (3178 observations) with discharge of soot were surveyed in both years. After merging the pollution data with other data, in our final sample, the numbers of firm-year observations with discharge of sulfur dioxide, waste water,

[34] At a national conference held by SEPA in April 2006, China's officials predicted that this turning point is US$3000 for GDP per capita.

Table 9
Alternative measurements of pollutants discharge.

Variables	(1) Log(oxynitride)	(2) Log(COD)	(3) Log(ammonia nitrogen)
Foreign	−0.3538*	−0.4563**	−0.5212*
	(0.1903)	(0.2099)	(0.2694)
Private	−0.2308	−0.1662	−0.0247
	(0.2243)	(0.2451)	(0.2561)
Public	−0.5342***	−0.3073	−0.6747***
	(0.2012)	(0.2148)	(0.2605)
Collectives	−0.1544	−0.2152	0.5011
	(0.2688)	(0.2444)	(0.3837)
Limited	−0.2454	−0.3007	−0.1001
	(0.1752)	(0.2265)	(0.2280)
Export	−1.0665***	−0.2510	−0.3701
	(0.2636)	(0.2465)	(0.2983)
Firm_size	−0.0689	−0.2594***	−0.1533**
	(0.0458)	(0.0538)	(0.0676)
Firm_age	−0.0435	0.0490	0.0696
	(0.0666)	(0.0713)	(0.1017)
ROA	1.6998	−3.0005	−7.3359*
	(3.7533)	(3.5140)	(4.0810)
Leverage	0.0325**	0.0156	0.0011
	(0.0145)	(0.0260)	(0.0463)
R&D	−4.9134	6.2172	−15.1801
	(10.6676)	(5.0390)	(10.9539)
Education	−0.5657*	−1.7051***	−1.1348*
	(0.3045)	(0.4012)	(0.5920)
Competition	−0.9657	−1.7995**	−1.1525
	(0.9374)	(0.7814)	(1.6388)
Local_protection	−0.0154	0.0862**	0.0335
	(0.0496)	(0.0426)	(0.0599)
Property_right	−0.8000**	−0.6938*	−0.4446
	(0.3520)	(0.3527)	(0.4584)
Pop_intensity	−3.3623	−5.8791***	−9.7808***
	(2.4819)	(1.8426)	(2.0418)
Unemployment	−0.4991	−3.7165	−3.4182
	(4.7280)	(4.6929)	(5.8366)
Gdp_per_capita	−0.0563	−0.2148*	−0.4041***
	(0.1160)	(0.1106)	(0.1307)
Gdp_per_capita2	0.0032	0.0193*	0.0402***
	(0.0118)	(0.0114)	(0.0140)
Industry dummy	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes
Observations	1576	1981	1136
R-squared	0.5253	0.5071	0.3805

Columns (1)–(3) show the OLS regressions with the logarithm of the amount of oxynitride, chemical oxygen demand (COD) and ammonia nitrogen scaled by sales as the dependent variable, respectively. Robust standard errors clustered with cities are in brackets.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

and soot drop to 1576, 1981, and 1136, and the corresponding number of firms that appear in both years reduce to 683, 551, and 566. To check whether the unbalance of our data is a serious problem, we drop firms that were only surveyed in either 2006 or 2007. As shown in columns 1–3 in Table 10, the results from the balanced data are similar to our main findings, suggesting that the data unbalance is not a big issue.

6.3. HHI index

Our main estimation does not find significant association between competition (measured by the HHI index) and firm-level pollution intensity. One possible explanation is that the cross-year variation in the HHI index is not sufficiently large to produce precise estimates, given that our model already controls for industry fixed effects (which captures any industry-specific factors that remain constant over time). Based on our own calculation, the value of HHI index increases by an average of 0.0012 between 2006 and 2007, while the average value in 2006 is 0.0076. Besides, when we estimate the regressions without industry fixed effects (column 4–6 in Table 10), the coefficient on the HHI index turns statistically significant and its negative sign implies that less competition (higher HHI) is associated with less pollution. However, the disappearance of

Table 10
Determinants of pollutants discharge: balanced panel.

DEPVAR	(1) Log(SO2)	(2) Log(water)	(3) Log(soot)	(4) Log(SO2)	(5) Log(water)	(6) Log(soot)
	Balanced panel			All sample		
Foreign	−0.6050***	−0.9139**	−0.5722**	−0.6799***	−0.4742*	−0.6917***
	(0.2008)	(0.4225)	(0.2297)	(0.2163)	(0.2726)	(0.2400)
Private	−0.3114	−0.4171	−0.0354	−0.8224***	0.1274	−0.4847*
	(0.2303)	(0.4752)	(0.2701)	(0.1994)	(0.3228)	(0.2601)
Public	−0.7910***	−0.7110*	−0.6301**	−0.9287***	−0.5618*	−0.7491***
	(0.2623)	(0.4226)	(0.2500)	(0.2313)	(0.3006)	(0.2687)
Collectives	−0.1797	−1.2172**	−0.3079	−0.5161**	0.2294	−0.4091
	(0.2908)	(0.5027)	(0.3884)	(0.2333)	(0.4101)	(0.3460)
Limited	−0.3919**	−0.7077	−0.3649	−0.6236***	−0.1565	−0.4361*
	(0.1887)	(0.4428)	(0.2205)	(0.1895)	(0.2590)	(0.2234)
Export	−1.0160***	−1.2597***	−1.6084***	−2.0030***	0.0313	−2.1685***
	(0.3472)	(0.3912)	(0.3823)	(0.2609)	(0.3142)	(0.2788)
Firm_size	−0.1250*	−0.9114***	−0.1296*	−0.4014***	−1.2588***	−0.4456***
	(0.0665)	(0.1268)	(0.0715)	(0.0448)	(0.0992)	(0.0535)
Firm_age	0.0314	0.0671	−0.1528	0.0709	0.3295***	−0.0654
	(0.0831)	(0.1471)	(0.1192)	(0.0861)	(0.1183)	(0.0931)
ROA	4.9116	−5.7616	6.9252	−6.2202*	−6.6653	−7.0102*
	(4.1993)	(6.4001)	(4.6451)	(3.5710)	(4.6777)	(3.6059)
Leverage	0.0185	0.0508	0.0168	0.0429**	0.0245	0.0460**
	(0.0188)	(0.0343)	(0.0205)	(0.0193)	(0.0313)	(0.0185)
R&D	−32.9467***	−15.8160	−28.6306**	−21.6527**	2.3030	−19.6486**
	(10.6960)	(12.5327)	(13.3656)	(10.3144)	(7.7871)	(8.1785)
Education	−0.7137*	−3.6139***	−1.4779***	0.3862	−5.7907***	−0.3057
	(0.3644)	(0.9378)	(0.4767)	(0.3890)	(0.5626)	(0.3387)
Competition	1.7062	−0.2541	0.9955	−3.0692***	−6.1624***	−4.2217***
	(1.1051)	(0.9857)	(1.0292)	(0.7282)	(1.2326)	(1.0629)
Local_protection	0.0315	0.1519*	0.1045	0.0333	0.1532**	0.0550
	(0.0625)	(0.0830)	(0.0690)	(0.0449)	(0.0604)	(0.0540)
Property_right	−0.0046	−0.2182	−0.2244	0.1746	0.2490	−0.3685
	(0.4365)	(0.5278)	(0.5226)	(0.4175)	(0.5754)	(0.4971)
Pop_intensity	−0.5720	−10.2958***	−4.8206	−1.3806	−5.7242*	−7.4398***
	(2.9346)	(3.5044)	(3.2555)	(2.0697)	(2.9862)	(2.2205)
Unemployment	−0.8624	−2.5413	−2.1655	−3.8078	−5.4595	−4.2184
	(4.9716)	(7.5447)	(5.3063)	(3.8468)	(6.3402)	(4.9038)
Gdp_per_capita	−0.0904	−0.5427***	−0.4473***	0.0380	−0.5902***	−0.2841**
	(0.1202)	(0.1680)	(0.1437)	(0.1249)	(0.1536)	(0.1384)
Gdp_per_capita2	−0.0013	0.0558***	0.0372**	−0.0132	0.0515***	0.0221
	(0.0125)	(0.0148)	(0.0150)	(0.0141)	(0.0137)	(0.0156)
Industry dummy	Yes	Yes	Yes	No	No	No
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1364	1102	1132	2297	1931	1967
R-squared	0.4405	0.6379	0.4423	0.1649	0.4462	0.2189

Columns (1)–(6) show the OLS regressions with the logarithm of the amount of SO_2, waste water and soot discharge as the dependent variable, respectively. For each regression in column (1)–(3), we require that firms have observations for two years (2006 and 2007) on the respective pollutant emission information. For each regression in column (4)–(6), we do not include industry fixed effects. Robust standard errors clustered with cities are in brackets.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

such relationship once we include industry fixed effects is suggestive of a high correlation between the HHI index and time-invariant industrial characteristics.

6.4. Property rights protection and local protectionism

Before the 1978 economic reform and open-door policy, the centralized fiscal system and planned economy were deeply rooted in China. At the beginning of the 1980s, the local authorities were granted the power to develop the local economy and ever since local protectionism has surged due to the incentive on local economic growth. Therefore, local protectionism has been a long-standing issue in China. The property right system is manifested by China's local protectionism feature. An examination of the local protection or property rights indices over a period of years shows that they have very small variations within a province or city across time, suggesting that these two variables tend to be pre-determined. Furthermore, because the objective of local protection is the product market, as well as factors that relate to the power division between the central and the local government, social security system and the property right system, rather than pollution itself (Li et al., 2003), the original variation of local protectionism, if it has any, should not be correlated with the pattern of pollution intensity in China. In addition, our dependent variable is firm-level pollution, which makes it hard to argue that one individual firm's pollutant emission will influence a whole province's protection policies or legal system.

Nonetheless, one may worry whether our measures of property rights protection and local protectionism are the most appropriate choices. Because the property rights protection is measured at the city level, and local protectionism is measured at the province level, these measures may fail to capture the within-city or within-province variation. Although this is possible, there is limited information on the degree of variation below the current levels, and these are the best measures we can use given the available data. Nonetheless, as a robustness check, we still try two alternative measures. In particular, we use the development of legal intermediate institutions as proxy for the quality of the legal system, and use the degree of market-

Table 11
Alternative measures of local protectionism and property rights protection.

DEPVAR	(1) Log(SO2)	(2) Log(water)	(3) Log(soot)	(4) Log(SO2)	(5) Log(water)	(6) Log(soot)
Foreign	−0.4063***	−0.8882***	−0.3579*	−0.4692***	−0.9984***	−0.4143**
	(0.1536)	(0.2564)	(0.2063)	(0.1577)	(0.2622)	(0.2080)
Private	−0.1020	−0.3176	0.2295	−0.1456	−0.4075	0.1892
	(0.1871)	(0.2965)	(0.2350)	(0.1900)	(0.3056)	(0.2363)
Public	−0.4431**	−0.7221***	−0.2669	−0.4830***	−0.7581***	−0.2700
	(0.1717)	(0.2376)	(0.2022)	(0.1788)	(0.2430)	(0.2049)
Collectives	0.0531	−0.5940*	0.1780	−0.0028	−0.6498**	0.0923
	(0.2042)	(0.3162)	(0.3195)	(0.2054)	(0.3219)	(0.3083)
Limited	−0.2738*	−0.5426**	−0.1311	−0.3356**	−0.6331**	−0.1737
	(0.1410)	(0.2576)	(0.1924)	(0.1472)	(0.2650)	(0.1944)
Export	−0.7285***	−0.8105**	−1.0889***	−0.7308***	−0.8429**	−1.0948***
	(0.2583)	(0.3267)	(0.2851)	(0.2582)	(0.3306)	(0.2834)
Firm_size	−0.1004**	−0.9435***	−0.1591***	−0.1077**	−0.9411***	−0.1575***
	(0.0414)	(0.0855)	(0.0490)	(0.0418)	(0.0861)	(0.0478)
Firm_age	0.0687	0.2105**	−0.0906	0.0548	0.1838**	−0.1120
	(0.0715)	(0.0933)	(0.0897)	(0.0725)	(0.0927)	(0.0887)
ROA	1.7503	−10.4962**	−0.2759	1.8762	−10.3978**	−0.7005
	(3.2997)	(4.6890)	(3.1279)	(3.3104)	(4.6383)	(3.1496)
Leverage	0.0156	0.0494**	0.0154	0.0159	0.0533**	0.0189
	(0.0163)	(0.0245)	(0.0157)	(0.0158)	(0.0247)	(0.0154)
R&D	−8.0873	−1.3035	−10.4526*	−8.4708	−0.8454	−9.2094*
	(8.0883)	(6.6926)	(5.4282)	(7.7417)	(6.6943)	(5.0546)
Education	−0.9975**	−3.8106***	−1.6090***	−0.9842**	−3.7823***	−1.6137***
	(0.3869)	(0.5827)	(0.3654)	(0.3852)	(0.5827)	(0.3640)
Competition	−0.0741	−1.6228	−0.8573	0.0471	−1.6890	−0.7080
	(1.0139)	(1.0468)	(1.2822)	(0.9571)	(1.0517)	(1.1673)
Local_protection	0.1031**	0.1663***	0.1517***			
	(0.0431)	(0.0552)	(0.0551)			
Property_right				−0.1654	−0.4190	−0.3469
				(0.3460)	(0.4634)	(0.4068)
Local_price_protection				0.7469**	0.3005	1.0239**
				(0.3571)	(0.5035)	(0.4457)
Legal interm inst devpt	−1.2710***	−0.8104	−0.5688			
	(0.4322)	(0.6192)	(0.6251)			
Pop_intensity	−1.3912	−5.5996**	−6.6661***	−2.3820	−6.3314***	−6.8739***
	(2.3355)	(2.7006)	(2.3606)	(2.0400)	(2.3730)	(1.9523)
Unemployment	−2.2694	−4.6480	−3.9185	−2.5320	-4.1226	−4.5371
	(3.4297)	(5.1716)	(4.4520)	(3.6245)	(5.3415)	(4.5256)
Gdp_per_capita	0.0120	−0.5370***	−0.3177**	−0.0443	−0.6234***	−0.3041**
	(0.1049)	(0.1259)	(0.1435)	(0.1117)	(0.1345)	(0.1486)
Gdp_per_capita2	−0.0099	0.0496***	0.0240	−0.0064	0.0557***	0.0216
	(0.0119)	(0.0116)	(0.0152)	(0.0121)	(0.0124)	(0.0162)
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
N	2297	1931	1967	2297	1931	1967
R-squared	0.4113	0.6083	0.3955	0.4089	0.6061	0.3968

Columns (1)–(3) show the OLS regressions with the logarithm of the amount of SO_2, waste water and soot discharge as the dependent variable, respectively, where "legal interm inst devpt" is used as an alternative measure for property rights protection. "legal interm inst devpt" is an index that measures the development of legal intermediate institutions for each province, with higher values indicating better legal system development. Columns (4)–(6) show the OLS regressions with the logarithm of the amount of SO_2, waste water and soot discharge as the dependent variable, respectively, where "local_price_protection" is used as an alternative measure for local protectionism. "local_price_protection" is an index that measures the degree of price protection by local government, with higher values indicating more local price protection. All of the other variables are defined in Appendix Table A1. Robust standard errors clustered with cities are in brackets.

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

determined price in the product market as proxy for local protectionism. These indices have also been widely used by academic scholars as proxies for institutional environment during China's marketization in the past few years. Both index variables are from the NERI index of Marketization of China's Provinces 2006 Report, measured at the province level, and with a higher value represents a better quality legal system or more local protectionism. The estimates reported in Table 11 are consistent with our main results, suggesting that our findings are robust to alternative measures.

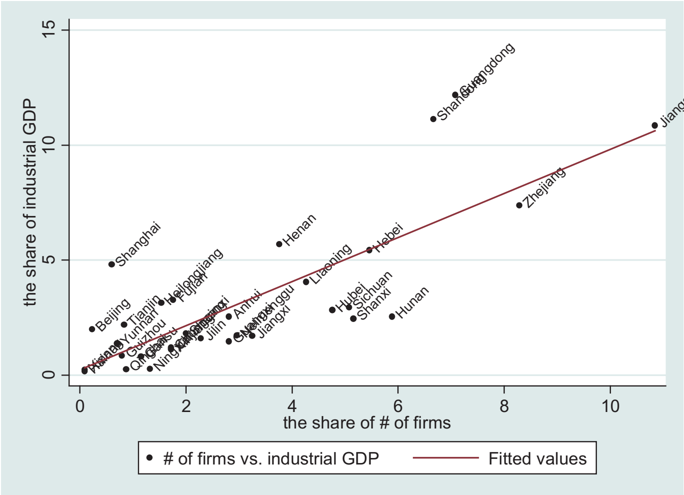

Fig. A1. Number of firms and the industrial GDP. *Note*: this figure depicts the correlation between the share (in percentage) of number of firms of each province in our final sample (*x*-axis) and the share (in percentage) of provincial industrial GDP in 2006 (*y*-axis).

Fig. A2. The map of china cities on sulfur dioxide discharge intensity. *Note*: The bigger the circle the more sulfur dioxide pollution in the indicated city.

However, it is still possible that property rights protection and local protectionism might be related to some city- or province-level policies (or government features) that can affect local industrial pollution. Although we attempt to mitigate such

Table A1
Variable definition and data source.

Variable	Source	Definition
Pollutants		
SO2	China's State Environmental Protection Agency (SEPA) 2006, 2007	Amount of discharged SO_2 (ton))/sales (100 million RMB)
SO2_over	Idem	Amount of discharged SO_2 over standards (ton)/sales (100 million RMB)
Wastewater	Idem	Amount of discharged wastewater (ton)/sales (10,000 RMB)
Wastewater_over	Idem	Amount of discharged wastewater over standards (ton)/sales (10,000RMB)
Soot	Idem	Amount of discharged soot (ton)/sales (100 million RMB)
Soot_over	Idem	Amount of discharged soot over standards (ton)/sales (100 million RMB)
Oxynitride	Idem	Amount of discharge oxynitride (ton)/sales (100million RMB)
COD	Idem	Amount of chemical oxygen demand (COD) (ton)/ sales (100 million RMB)
Ammonia nitrogen	Idem	Amount of ammonia nitrogen (ton)/ sales(100 million RMB)
Ownership		
SOE	The First Economic Census of China (2005)	Dummy variable, =1 if the firm is registered as state-owned enterprise, including alliances of SOEs and unlisted state-owned limited companies; =0, otherwise
Foreign	Idem	Dummy variable, =1 if the firm is registered as joint ventures, cooperatives with HK, Macau, Taiwan (HMT) or foreign investors; or HMT wholly owned companies, HMT shareholding (limited) companies; or Wholly foreign owned companies; or Foreign shareholding (limited) companies; =0, otherwise
Private	Idem	Dummy variable, =1 if the firms is registered as private limited companies, private shareholding companies, proprietorship or partnership company; =0, otherwise
Public	Idem	Dummy variable, =1 if the firm is a public-listed company; =0, otherwise
Collectives	Idem	Dummy variable, =1 if the firm is registered as collectives or alliances of collectives; =0, otherwise
Limited	Idem	Dummy variable, =1 if the firm is registered as unlisted non-state-owned limited companies; =0, otherwise
Firm-level variables		
Export	The First Economic Census of China (2005)	=total export/ total sales
Firm_size	SEPA 2006 and 2007	The logarithm of the number of employees by the end of the year
Firm_age	Idem	The logarithm of the age of the firm
ROA	Idem	=EBIT/Assets
leverage	Idem	=Debt/Equity
R&D	The First Economic Census of China (2005)	=R&D expenses/sales
Education	The First Economic Census of China (2005)	The ratio of number of employees with college diploma or higher degrees
Other variables		
Competition	The NBS Enterprise Database	Concentration Ratios calculated from NBS Enterprise Database. The Herfindahl–Hirschman Index (HHI) equals the sum of the squared market shares of each firm in the industry. Note that this index is a function of all firms' market shares. HHI has lower limit zero in case of perfect competition (firms $\rightarrow \infty$ and shares $\rightarrow 0$) and upper limit of one in case of monopoly (1 firm with 100% share)
Local_protection	The NERI Index of Marketization of China's Provinces 2006 Report	Measurement to reduce local protection in product market, higher value indicates higher entry barrier, at province level measured for year 2003
Property_right	China Governance, Investment Climate, and Harmonious Society: Competitiveness Enhancements for 120 Cities in China, by the World Bank (2006)	Property right protection index, higher value indicates better property right protection, at city level measured for year 2003
Pop_intensity	China City Statistical Year Book (2006, 2007)	=population (10,000)/land area (km^2), at city level
Unemployment	Idem	The unemployment rate at city level
Gdp_per_capita	Idem	GDP per capita at city level (10,000RMB)
Gdp_per_capita2	Idem	The squared term of GDP per capita at city level (10,000RMB)

Table A2
Cross-sample comparison on firm characteristics and ownership.

Variable	Firm characteristics				Variable	Ownership			
	N	P25	Median	P75		*N*	P25	Median	P75
SO_2 emission sample									
Export	2297	0	0	0	Foreign	2297	0	0	0
Firm_size	2297	5.55	6.29	7.2	Private	2297	0	0	1
Firm_age	2297	2.08	2.56	3.22	Public	2297	0	0	0
ROA	2297	0	0.01	0.01	Collectives	2297	0	0	0
Leverage	2297	0	0.08	0.55	Limited	2297	0	0	1
R&D	2297	0	0	0					
Non-inclusive SO_2 sample									
Export	4715	0	0	0	Foreign	4798	0	0	0
Firm_size	3734	5.46	6.17	6.98	Private	4798	0	0	0
Firm_age	3728	2.08	2.48	3.18	Public	4798	0	0	0
ROA	3203	0	0.01	0.01	Collectives	4798	0	0	0
Leverage	4599	0	0.05	0.54	Limited	4798	0	0	1
R&D	4715	0	0	0	Limited	4798	0	0	1
Waste water sample									
Export	1931	0	0	0.05	Foreign	1931	0	0	0
Firm_size	1931	5.69	6.39	7.29	Private	1931	0	0	0
Firm_age	1931	2.08	2.64	3.26	Public	1931	0	0	0
ROA	1931	0	0.01	0.01	Collectives	1931	0	0	0
Leverage	1931	0	0.08	0.52	Limited	1931	0	0	1
R&D	1931	0	0	0					
Non-inclusive waste water sample									
Export	5081	0	0	0	Foreign	5164	0	0	0
Firm_size	4100	5.44	6.12	6.93	Private	5164	0	0	0
Firm_age	4094	2.08	2.48	3.14	Public	5164	0	0	0
ROA	3569	0	0.01	0.01	Collectives	5164	0	0	0
Leverage	4965	0	0.05	0.55	Limited	5164	0	0	1
R&D	5081	0	0	0					
Soot emission sample									
Export	1967	0	0	0	Foreign	1967	0	0	0
Firm_size	1967	5.6	6.38	7.28	Private	1967	0	0	0
Firm_age	1967	2.08	2.64	3.26	Public	1967	0	0	0
ROA	1967	0	0.01	0.01	Collectives	1967	0	0	0
Leverage	1967	0	0.09	0.58	Limited	1967	0	0	1
R&D	1967	0	0	0					
Non-inclusive soot sample									
Export	5045	0	0	0	Foreign	5128	0	0	0
Firm_size	4064	5.44	6.14	6.93	Private	5128	0	0	0
Firm_age	4058	2.08	2.48	3.18	Public	5128	0	0	0
ROA	3533	0	0.01	0.01	Collectives	5128	0	0	0
Leverage	4929	0	0.05	0.53	Limited	5128	0	0	1
R&D	5045	0	0	0					

Note: This table compares firm characteristics and ownership between pollutant (SO_2, waste water or soot) emission sample and non-inclusive pollutant emission sample.

biases by including several city-level socioeconomic variables, we cannot complete guard against the above possibility. Therefore, one should be cautious when drawing any causal inferences based on our estimates.

6.5. Other empirical issues

During the data merging, our sample size drops dramatically from over 7000 to 2842 mainly due to missing information on (city-level) property rights index and firm characteristics (e.g. ROA and leverage). However, it is quite reassuring that the statistics of many variables such as firm size, firm performance and ownership are very similar between firms included in our sample and those dropped during the sample construction (see Appendix Table A2). This suggests that the dropped observations are not systematically different from the sample we use. In addition, we also experiment with a large sample by replacing the missing values of property rights index with the province average, and replacing the missing firm characteristics with the industry average. Our results do not change significantly.[35]

As the self-reported data on pollution emissions are used as the basis for pollution fee charges, firms would have incentives to manipulate or under-report their discharges, thus leading to measurement error in our dependent variables.

[35] These results are available from authors upon request.

Although this is a legitimate concern (as in many other studies relying on self-reported information) that we cannot completely rule out, the costs of misreporting could be very high because firms participating in these surveys are under the direct supervision (and strict inspection) of the MEP.

Finally, unlike other pollutant discharges that are directly reported, the measure of sulfur dioxide discharge is based on an indirect method with the consumption of energy resources multiplied by the associated sulfur dioxide emission coefficients.[36] Regardless, the results for different pollutants are qualitatively similar, suggesting that the pollution dataset is mostly reliable.

7. Conclusion

In this study, we use a unique firm-level dataset covering over 100 cities in China to study factors that are associated with Chinese industrial pollution intensity. We find that foreign firms have lower pollutant discharge intensity than SOEs. This effect is more pronounced for sulfur dioxide and soot pollution in heavy polluted industries, and more pronounced for waste water in coastal cities. These results suggest that a policy that targets foreign firms more harshly in China's effort to reduce industrial pollution, as implied by some government reports, would be misguided. Our findings that public-listed firms also pollute less than SOEs suggest that under the scrutiny of public investors, public-invested firms take more SCR on pollution control. We also find that local protectionism is a major cause of pollution, and better property rights protection is negatively related to pollution especially when a firm discharges pollutants over and above the national standard. Therefore, better institutional control in the form of lower entry barriers across regional markets and more effective law enforcement are promising ways of curbing China's pressing environmental problems during its current stage of economic development. In addition, we also document that firms of a larger size with more educated employees tend to pollute less.

Even though our data alone do not support casual explanation, our findings are consistent with the theoretical predictions and previous empirical findings such as foreign firms pollute less (Wang and Jin, 2002; Liang, 2008) than SOEs, firms of a larger size tend to pollute less (Holladay, 2010), and firms that export more pollute less (Milner and Xu, 2009; Holladay, 2010). This suggests that these associations may be consistent with causal explanations based on prior literatures.

To the best of our knowledge, our paper is one of the first to use nationwide firm-level pollutant discharge amounts (as opposed to pollution fees) to measure pollution intensity in China. China's economy is on a historic rise, but the resulting environmental damage could wipe out all of its success if China's leaders do not take effective initiatives now. We hope that our study has provided some insights to China's government by depicting a relatively complete picture of China's manufacturing pollution situation and providing useful policy implications.

Acknowledgments

We are grateful to Editor Daniel Berkowitz, two anonymous reviewers, Gregory Chow, Jin Wang, and Yi Zhu for their helpful comments and suggestions. L. Jiang and P. Lin gratefully acknowledge Lingnan University for financial support of this project.

Appendix A

See Figs. A1 and A2 and Tables A1 and A2.

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[36] For example, for the thermal power plant, the sulfur dioxide emission = the amount of coal burned $\times$ sulfur content (in percentage) $\times$ 0.8 $\times$ 2 $\times$ (1 − desulfurization degree). See *The Working Plan for Major Pollutant Emission Statistics Method* by the MEP, Issue 15, December 7, 2007.

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