Industrial output and air pollutant emissions: A study of Chinese cities

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ABSTRACT. With data on 287 cities from 2003 to 2010, this study investigates whether industrial firms of different types of ownerships differ in sulfur dioxide emissions across city administrative levels and geographical regions in China. Weighted least square regression results suggest that both Hong Kong, Macau, and Taiwan (HMT) industrial firms and ethnically non-Chinese foreign firms are associated with statistically significant higher sulfur dioxide emissions in municipalities. HMT firms tend to emit less in southern China, where they are close to home, while foreign firms tend to emit less in other regions.

JEL Classification: Q53, Q56, R11
Keywords: Industrial output, foreign direct investment, environment, air pollution, industrial sulfur dioxide emission, China

1. Introduction

To the world, China has achieved miraculous economic growth over the past fewdecades. However, such economic achievement comes with a heavy cost – environmental degradations. Close to two-thirds of the 300 Chinese cities tested in 2002 failed to meet the air quality standards set by the World Health Organization (WHO) (Cole et al, 2011). In 2006, the environmental external costs due to air pollutants in major Chinese cities were about US$ 20.15 billion or an equivalent of 2.28% of China's Gross Domestic Product (GDP), with damages to human health being the main costs (Wei et al, 2009). Several factors have contributed to the greater tension between economic development and environmental quality in China. For one, evaluation and promotion criteria of local government officials have traditionally been based on local economic growth (Zheng & Kahn, 2013). A provincial or city head who manages to

achieve impressive GDP growth is more likely to be promoted to the next cadre, which has led many local governments to blindly pursue high growth rate and lose sight of potential environmental costs. Many local governments have even purposefully lowered local environmental standards or do not enforce regulations enough in order to encourage more productions and compete for a greater amount of investments which otherwise may be deterred by higher pollution abatement costs (Zheng & Kahn, 2013). Besides, the prevalent use of dirty fuel is also culpable. For instance, China still generates more than 70% of its electricity using coal despite the fact that coal burning emits large quantities of polycyclic aromatic hydrocarbons (PAHs) and other pollutants (Zheng & Kahn, 2013). Moreover, facing loose regulations, industrial firms lack incentives to uphold sound environmental practices and often resort to inferior technologies and dirty fuel options to reduce production costs.

As China has achieved rapid industrialization over the past several decades, industrial firms operating in China can be classified into three groups by ownership: domestic firms, Hong Kong, Macau and Taiwan (HMT) firms, and other foreign firms mainly from the OECD countries. Understanding which group of firms is relatively more polluting in China is crucial to making decisions on foreign direct investment (FDI) and to setting appropriate regulatory policies in order to achieve sustained development. Besides, cities in China can be further classified by administrative levels and geographical regions, and cities tend to differ significantly across administrative levels and regions. However, to my knowledge no existing literature has examined whether the effects of industrial output by each group of firms on pollution differ across city administrative levels and geographical regions. Investigations across administrative levels and regions could potentially add more dimensions to our understanding of the issue.

Therefore, in this paper I will investigate whether industrial firms of the aforementioned three types of ownerships differ in industrial sulfur dioxide emissions across city administrative levels and geographical regions in China. Industrial sulfur dioxide is the measure of air pollution in this study because of data availability and consistency with previous literature. The largest sources of sulfur dioxide emissions are from fossil fuel combustion at power plants and other industrial facilities (Environmental Protection Agency [EPA], 2015). Sulfur dioxide is associated with a number of damaging effects on the respiratory system and is also a major precursor of acid rain (Clean Air Trust, 2015). It is important to understand the interplay between firm ownership and sulfur dioxide emissions at different city levels and across regions to help local governments form sound policies regarding FDI and environmental protection.

Using Weighted Least Square (WLS) regressions on panel data of 287 China cities from 2003 to 2010, I find that industrial firms owned by Hong Kong, Macau and Taiwan (HMT) and by other foreign industrial firms are both associated with higher industrial sulfur dioxide emissions in municipality-level cities than domestic firms. Besides, HMT industrial firms emit significantly less sulfur dioxide in the South, where they are close to home, while other foreign firms are associated with significantly lower emission levels in the Southwest and the North.

The rest of the paper is organized as follows. Section 2 reviews previous literature on China's economic development and environmental quality. Section 3 discusses the data, measurement, and empirical method. Section 4 reports empirical findings. Section 5 concludes the discussion.

2. Literature review

In literature, two competing hypotheses exist about the effects of FDI on a host country's environment. The pollution haven hypothesis postulates that large multinational firms from industrialized nations are attracted to developing nations with less stringent environmental regulations so as to reduce pollution abatement costs associated with their productions and in this way FDI will increase local pollutions (Cole et el, 2011). In contrast, the pollution halo hypothesis posits that multinational companies may reduce local pollutions because of their better management practices, cleaner production processes, and more advanced environmental technologies (Wang & Chen, 2014). Literature on the relationship between economic growth, openness, and the environment in China has emerged over the past few years under the increasing tension between China's economic development and environmental quality. A particular theme of literature has focused on the impact of FDI on the environment. Using data on 231 China cities from 1996 to 2003, Feng (2008) finds a negative correlation between FDI and industrial sulfur dioxide emissions, supporting the view that FDI may be beneficial to the environment. This echoes Kirkulak et al (2011) who study 286 cities from 2001 to 2007 and also find that the presence of FDI reduces industrial sulfur dioxide emissions. Zheng, Kahn, and Liu (2010) use data across 35 major Chinese cities over 2004 to 2006 and find a negative correlation between a city's FDI inflows and its ambient air pollution level. However, He (2006, 2009) finds evidence that pollution and FDI are positively correlated. Just like the larger debate on the pollution haven hypothesis and the pollution halo hypothesis, literature so far has not achieved a consensus on the effects of FDI on China's environment. This unsettled debate motivates me to explore this topic further.

One stream of literature has taken a special interest in the Environmental Kuznets Curve (EKC) hypothesis, which suggests an inverted U-shaped relationship between a country's environmental degradation and per capita income. According to the EKC curve, pollution increases up to a certain level and then decreases as per capita income grows (Zheng & Kahn, 2013). For instance, Shaw et al (2010) study 99 Chinese cities from 1992 to 2004 to estimate the EKC relationship and find that the EKC hypothesis is supported in the case of ambient concentrations of SO2. In addition, Li and Tu (2014) find that China's urban pollution can be explained by scale effect, composition effect, and technique effect, a framework introduced by Grossman and Krueger (1993), with technique effect being the dominant of the three. According to this framework, scale effect refers to the impact from increased output or economic activities on pollution due to freer trade. Composition effect refers to the impact on pollution of trade liberalization as a country changes the mix of its production towards those products where it has a comparative advantage. Technique effect refers to the impact on pollution as freer trade introduces cleaner goods, services, and technologies and also as the society demands better environmental standards when their income increases. Inspired by these studies, I also built my model in a way to test the existence of an EKC relationship and capture the triple effects of scale, composition, and technique.

Some literature has attempted to conduct regional analysis for China. For instance, Kirkulak et al (2011) have categorized China into three regions, namely east, center, and west, and they find that the impact of FDI on industrial SO2 emissions is not significant in central and western China. Similarly, Yang et al (2013) study 28 Chinese provinces from 1995 to 2010 using the same east-center-west regional categorization and find that provincial emission levels decrease from east to west. Although these findings are reasonable, the regional categorization

used is arguably still too broad given China's large size. A more detailed regional categorization of China will potentially offer us a more nuanced understanding of differences across regions. In this light, Shaw et al (2010) breaks China into seven regions and find that ambient sulfur dioxide concentrations differ significantly across regions. However, Shaw et al use the regional dummy variables as an alternative to city-specific fixed effects to capture cross-regional effects; they do not consider different types of firm ownership nor investigate whether the effects of FDI on sulfur dioxide concentrations differ across regions. Nevertheless, Shaw et al (2010) represents the only study in literature that uses a nuanced regional categorization of China and I adopt the same regional categorization in my study.

Furthermore, literature on the relative pollution intensity among industrial firms of different ownerships in China is still relatively nascent. Cole et al (2011) study the relationship between economic growth, FDI, and industrial pollution in China using 112 cities from 2001 to 2004. They find that industrial output has a strong positive impact on emissions, and that the effects differ across different firm ownerships. According to their results, the share of output of domestic firms and foreign firms are associated with higher industrial sulfur dioxide emissions in a statistically significant manner, but output from HMT firms is statistically insignificant. Similarly, Wang and Chen (2014) study the relationship between FDI, institutional development, and industrial sulfur dioxide emissions for 287 Chinese cities from 2002 to 2009. They find that investments from OECD countries are associated with higher sulfur dioxide emissions, while investments from Hong Kong, Macau, and Taiwan (HMT) show no significant impact. They argue that HMT firms are likely more devoted to developing long term relationships with their Chinese host cities than foreign firms. Li and Tu (2014) find that HMT firms produce fewer industrial sulfur dioxide emissions, while foreign firms have a non-significant impact on

emissions. One interpretation according to them is that ethnically Chinese firms are more susceptible to reputation risks when they operate in China, and therefore they are more sensitive to environmental standards.

Building on previous literature, I want to further explore the effects of industrial output of different firm ownerships on industrial sulfur dioxide emissions in Chinese cities and examine whether the effects differ across geographical regions and city administrative levels. To my knowledge no literature thus far has examined whether industrial firms of different ownerships have differential impacts on air pollutions depending on the region or city administrative level they operate in. Therefore, this study represents a first attempt to address this question.

3. Data and methodology

3.1. Data sources and variables

Most industrial activities and pollution in China take place in cities (Li & Tu, 2014). Therefore, similar to most previous literature, I used city-level data instead of aggregated provincial-level data to minimize data inconsistency and data measurement problems. The data source of this study is China City Statistical Yearbook published by National Bureau of Statistics of China (2004-2011). The China City Statistical Yearbook is the primary source for city-level data in China and has been the primary data source for previous literature on Chinese cities. It contains city-level socioeconomic data for 287 major cities in China on an annual basis and the years I have access to are 2003 to 2010. Figure 1 maps the locations of these 287 cities, with each red dot representing an individual city.

Figure 1: Cities in this study

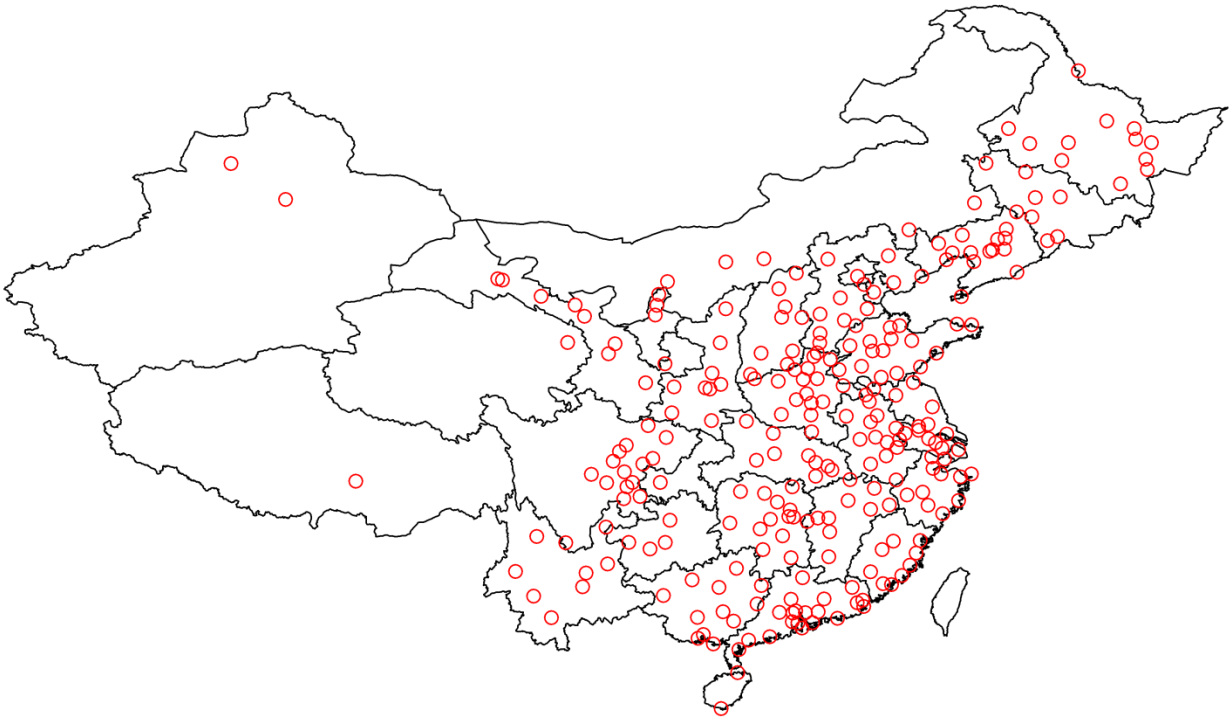


Table 3.1 lists the variables used for this study and Table 3.2 provides summary statistics. Since the China City Statistical Yearbook reports all data in the current year, I used China's GDP deflator published by the World Bank to deflate all nominal values to real values using 2000 as the base year. Therefore, all summary statistics presented in Table 3.2 are real values.

The dependent variable in my study is industrial sulfur dioxide emissions measured in tons. This variable designates sulfur dioxide emissions strictly from industrial processes and does not include emissions from other sources such as motor vehicle emissions, and it is the aggregate sum of self-reported sulfur dioxide emission levels collected from individual industrial firms in each city. Because the sulfur dioxide emission data are self-reported, firms may have incentives to underreport their emission levels. However, industrial sulfur dioxide is the only air pollutant reported in the dataset and many previous studies have used it as the dependent variable. To be

consistent with previous literature, I also use industrial sulfur dioxide emissions as my dependent variable in this study but acknowledge that its measurement might be underreported to some extent.

The following are my independent variables, and again all variables are measured at city level on an annual basis. Total industrial output, measured in 10,000 yuan, is the entire output by industrial firms in a city in a given year. I included it to capture the scale effects of industrial output on industrial sulfur dioxide emissions. Consistent with Wang and Chen (2014), HMT share and foreign share are defined as the percentage points of total industrial output generated by HMT industrial firms and by foreign industrial firms respectively. According to Wang and Chen (2014), this output-based measure of FDI is better than the value of FDI inflows reported in the dataset, because FDI inflows to China are often overstated. In my dataset, HMT share ranges from 0 to 83% with a mean value of 6.8% and foreign share ranges from 0 to 78% with a mean value of 9.5% across cities over the study period. Since the percentage point of total industrial output produced by domestic firms, HMT share, and foreign share always add up to 100, the share by domestic firms is treated as the base category in my regression. Building on previous literature, I also included the cities' per capita GDP, its square term, capital to labor ratio, and the proportion of people working in "dirty sectors" as my control variables. Per capita GDP and its square should capture the technique effects resulting from higher income levels and allow us to verify the existence of the Environmental Kuznets Curve (EKC). Capita to labor ratio is calculated as the ratio of net value of total fixed assets of industrial firms to total number of employees of the industrial firms in a city in a given year. Share of employment in dirty sectors refers to the proportion (%) of employees in mining, manufacturing, and utilities to total number of employees, since these three sectors are reported to have the highest sulfur dioxide emission

levels (Li & Tu, 2014). Because the output value of each individual sector is not available in the dataset, I used the proportion of people working in these sectors instead to proxy for the dirtiness of industry in a city.

Table 3.1 Variables and definitions in this study

Variable	Definition
Industrial SO2 emission	Total emission of industrial sulfur dioxide (ton) of the city
HMT share	Percentage (%) of total industrial output produced by Hong Kong, Macau, and Taiwan (HMT) industrial firms in the city
Foreign share	Percentage (%) of total industrial output produced by foreign industrial firms in the city
Total industrial output	Value (10,000 yuan) of total industrial output of the city
Per capita GDP	Per capita GDP (yuan) of the city
Capital to labor ratio	Net value of fixed asset (10,000 yuan) per worker in industrial firms in the city
Share of employment in dirty sectors	Percentage (%) of people employed in mining, manufacturing, and utilities out of total employment level of the city
Administrative level	Administrative level of the city, ordered in four categories: 1: Municipalities 2: Sub-provincial-level cities 3: Other provincial and autonomous region capitals, all at prefecture-level 4: All other prefecture-level cities
Region	Geographical region to which the city belongs, out of seven regions: 0: Southwest 1: North 2: East 3: South 4: Center 5: Northeast 6: Northwest

Table 3.2 Summary statistics

Variable	N	Mean	SD	Min	Max
Industrial SO2 emission (ton)	2274	63014.15	63692.45	12.00	6.83e+05
HMT share (%) of industrial output	2144	6.77	9.61	0.00	83.02
Foreign share (%) of industrial output	2173	9.52	11.11	0.00	77.99
Total industrial output (10000 yuan)	2283	9.83e+06	1.76e+07	26858.07	2.02e+08
Per capita GDP (yuan)	2280	16067.16	12960.78	1796.43	1.17e+05
Capital to labor ratio (10000 yuan/worker)	2257	1.48e+05	1.27e+05	246.18	2.69e+06
Share (%) of employment in dirty sectors	2188	34.23	13.50	5.50	80.86
Administrative level	2296	3.79	0.59	1.00	4.00
Region	2296	3.03	2.01	0.00	6.00

Besides, in China, cities are categorized according to their relative economic importance into three administrative levels, namely the municipality level, the sub-provincial level, and the prefecture level. Municipalities, including Beijing, Shanghai, Tianjin, and Chongqing, are the economically most advanced cities and have the same rank as provinces. Sub-provincial-level cities are just one level below municipalities and include some provincial capital cities and a few other economically highly important cities. Most cities fall under the prefecture-level, which consist of some provincial capital cities not as economically developed as those at the sub-provincial level as well as hundreds of other regular small and medium-sized cities. Table 3.3 lists the categorization of China city administrative levels in my study and the number of cities at each level. City administrative levels are coded as dummy variables which equal to 1 if the city is a municipality, 2 if the city is a sub-provincial-level city, 3 if the city is a provincial or autonomous region capital city at the prefecture level, and 4 if the city is just a normal prefecture-level city.

Table 3.3 City administrative levels and number of cities at each level

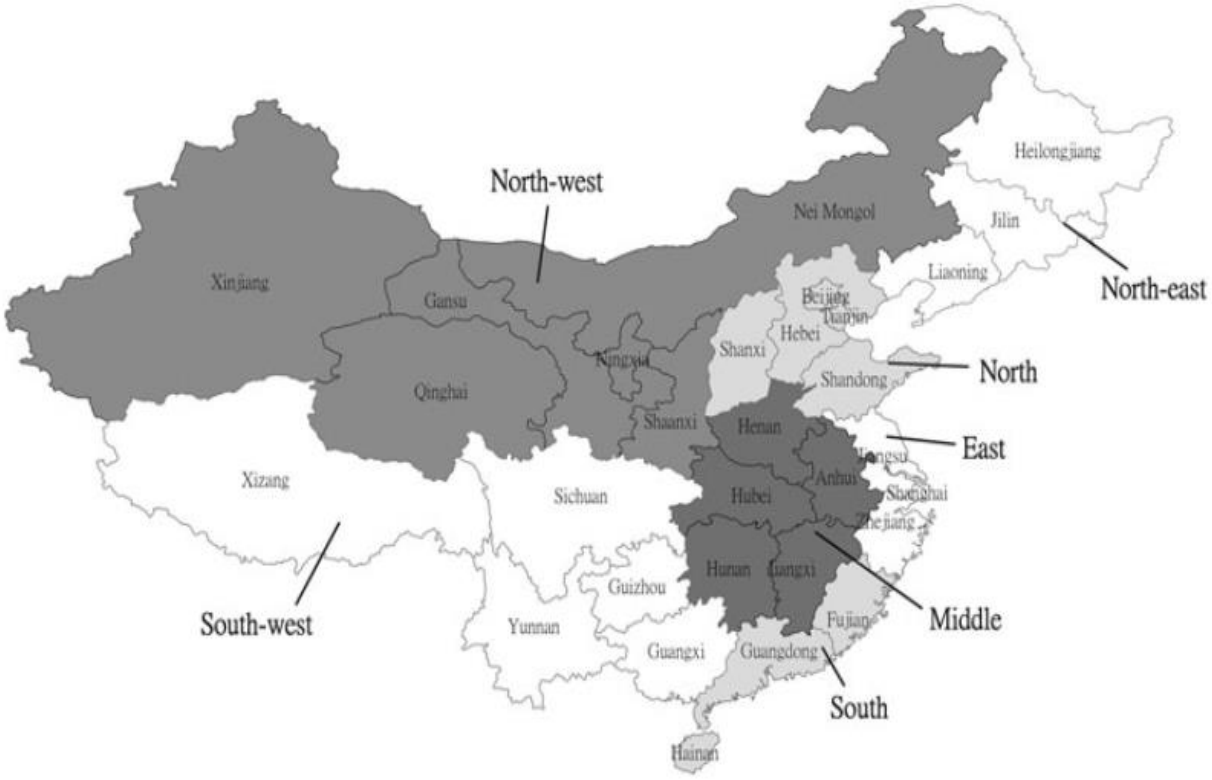
Administrative level	**Category**	**Number of cities**
Level 1	Municipalities	4
Level 2	Sub-provincial-level cities	15
Level 3	Provincial and autonomous region capital cities (prefecture level)	17
Level 4	Other prefecture-level cities	251

Moreover, I have grouped these 287 cities into seven geographical regions following the same regional categorization by Shaw et al (2011). Table 3.4 lists these seven regions and the region dummy variable ranges from 0 to 6 depending on which geographical region a city belongs to. Figure 2 provides a map of these seven regions.

Table 3.4 Geographical regions and number of cities in each region

Region label	**Region name**	**Number of cities in this region**	**Provinces (or province-level municipalities) in this region**
0	Southwest	46	Chongqing, Sichuan, Guizhou, Guangxi, Yunnan, Tibet
1	North	41	Beijing, Tianjin, Hebei, Shanxi, Shandong
2	East	25	Shanghai, Zhejiang, Jiangsu
3	South	32	Fujian, Guangdong, Hainan
4	Center	70	Henan, Hubei, Hunan, Anhui, Jiangxi
5	Northeast	34	Heilongjiang, Jilin, Liaoning
6	Northwest	39	Xinjiang, Gansu, Qinghai, Ningxia, Shaanxi, Inner Mongolia

Figure 2: Regional categorization of China
Source: Shaw et al (2011)



3.2 Regression methods

For my regressions, I transformed all continuous variables with natural logarithm, unless the variable was already measured in percentage point, to ensure that the coefficients fall within easy-to-interpret range and also to partly resolve outlier and heteroskedasticity problems. I am interested in observing whether firms of different ownerships are associated with different industrial sulfur dioxide emission levels across city administrative levels and geographical regions. I therefore ran the following regressions.

a)

$$log(SO2\ emission)_{it} = \alpha + \beta_1 HMT\ share_{it} + \beta_2 Foreign\ share_{it} + X_{it}\gamma + \mu_i + \delta_t + \varepsilon_{it}$$

Regression a) is my baseline regression. This regression model adopts a basic form similar to the model used by Wang and Chen (2014). The subscript i denotes each of the 287 cities and t denotes each year of the study period from 2003 to 2010. The dependent variable is total industrial sulfur dioxide emissions. α is the intercept. Variables HMT share and foreign share are percentage points of a city's total industrial output generated by HMT industrial firms and by foreign industrial firms respectively. X_{it} is a vector of control variables that include total industrial output, per capita GDP, the square term of per capita GDP, capital to labor ratio, and share of employment in dirty sectors; γ is a vector of parameters. The control variables all underwent a natural log transformation except for the share of employment in dirty sectors, whose measurement was already in percentages. I used both city- and time-specific fixed effects, with μ_i and δ_t denoting any unobservable city- and time-specific effects not included in the regression. Lastly, the ε_{it} term represents the remaining disturbance that varies over cities and time. A Breusch-Pagan test shows that heteroskedasticity exist in this regression, and I therefore ran this regression using robust standard errors.

b)

$$\begin{aligned} log(SO2\ emission)_{it} &= \alpha + \sum_{c=1}^{4}\beta_1^c HMT\ share_{it} * Level_{ci} + \sum_{c=1}^{4}\beta_2^c Foreign\ share_{it} * Level_{ci} \\ &+ \sum_{r=0}^{5}\beta_3^r HMT\ share_{it} * Region_{ri} + \sum_{r=0}^{5}\beta_4^r Foreign\ share_{it} * Region_{ri} \\ &+ X_{it}\gamma + \mu_i + \delta_t + \varepsilon_{it} \end{aligned}$$

In regression b), I investigated how the effects of industrial firm ownership on sulfur dioxide emissions may differ across city administrative levels and geographical regions. In this regression, X_{it} is the same set of control variables as in the baseline regression, and I again applied both city- and time-specific fixed effects to control for any unobservable city- or time-specific effects not already included in the regression. In this regression, I interacted HMT share and foreign share with each of the four city administrative level dummy variables separately. $Level_c$ denotes the city administrative level, with c=1, 2, 3 and 4 respectively for municipalities, sub-provincial-level cities, prefecture-level capital cities, and regular prefecture-level cities. I also interacted HMT share and foreign share with each regional dummy variable separately. $Region_r$ is the regional dummy and r ranges from 0 to 5 for Southwest, North, East, South, Center, and Northeast respectively. Notice that one region, in this case the Northwest, is automatically dropped out as the reference group because all observations of HMT share and foreign share have already appeared once in the interactions with administrative levels. β_1^c, β_2^c, β_3^r and β_4^r are the coefficients of interest.

Moreover, for regressions b), I was concerned with the problem of heteroskedasticity because the variances of the error terms for each observation might differ depending on which city administrative level and geographical region were relevant for each observation. For instance, cities at higher administrative levels such as the municipality level and the sub-provincial level tend to be more similar in many aspects because they have achieved similarly high development stage with comparable economic structure. In contrast, the vast number of cities at lower administrative levels are more diverse in terms of economic development stage and tend to have greater city-to-city differences. Therefore, variations of unexplained industrial SO2 emission in the error terms are likely to be larger for cities at lower administrative levels

than for those at higher levels. By a similar reasoning, variations of unexplained industrial SO2 emission in the error terms are also likely to differ between cities in different regions. A Breusch-Pagan test showed that administrative level dummies and region dummies had indeed introduced heteroskedasticity in this regression. To correct for this, I ran a Weighted Least Square (WLS) regression for regression b). The advantage of WLS regression over the use of robust standard errors is that WLS regression would address heteroskedasticity arising from city administrative levels and geographical regions more directly and give more precise estimates of the regression coefficients. The weights used are the estimated variances of the error terms for each observation, with the assumption that those variances differ depending on which administrative level and geographical region are relevant for each observation. I will report all my empirical findings in Tables 4.1 and 4.2 in the following section.

4. Empirical Results

Column 1 of Table 4.1 reports the results for my baseline regression without including the proportion of people employed in dirty sectors as one of the independent variables. The model specification is similar to that of Wang and Chen (2014), but I unfortunately did not have access to data on the variables measuring institutional development that they have used in their study. As a result, our results do not completely align. In column 1 of Table 4.1, we observe that the coefficient of HMT share is negative and statistically significant at 10% level. The coefficient suggests that if one percentage point of total industrial output switches from domestic to HMT ownership, we may expect industrial sulfur dioxide to decrease by 1.3%, keeping all other independent variables constant. This result suggests that HMT industrial firms tend to be less polluting than other foreign firms, and this is consistent with what Wang and Chen (2014)

find. However, after I added in the proportion of people employed in dirty sectors following Li and Tu (2014) to form my baseline regression, the coefficient of HMT share became statistically insignificant while the coefficient for dirty sector became statistically significant at 10% level as seen under column 2. This finding suggests that HMT industrial firms might have been associated with lower sulfur dioxide emissions because they are less concentrated in dirty sectors. In both regressions, no statistically significant linear dependence of industrial sulfur dioxide emissions on foreign share was detected.

Table 4.1 Baseline regressions

Dependent variable: Log industrial SO2 emission

	(1)	(2)
VARIABLES	Baseline without dirty sector	Baseline
HMT share	-0.0133*	-0.0102
	(0.00802)	(0.00745)
Foreign share	-0.00340	-0.00347
	(0.00419)	(0.00425)
Log total industrial output	0.393***	0.331***
	(0.129)	(0.118)
Log per capita GDP	0.0994	0.234
	(0.583)	(0.590)
Log per capita GDP square	-0.0157	-0.0178
	(0.0285)	(0.0292)
Log capital to labor ratio	-0.00187	0.00924
	(0.0346)	(0.0360)
Share of dirty sectors		0.00972*
		(0.00521)
Constant	5.227**	4.624*
	(2.593)	(2.730)
Observations	2,047	1,956
R-squared	0.163	0.170
Number of city_id	284	284
Year FE	YES	YES
City FE	YES	YES

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4.2 WLS regressions across city administrative levels and regions

Dependent variable: Log industrial SO2 emission

	(1)	(2)	(3)
VARIABLES	Across levels	Across regions	Across levels and regions
HMT share × Southwest		0.00825	-0.0172
		(0.0104)	(0.0246)
HMT share × North		-0.00199	-0.0255
		(0.00561)	(0.0232)
HMT share × East		-0.00735	-0.0349
		(0.00769)	(0.0242)
HMT share × South		-0.0502***	-0.0716***
		(0.00925)	(0.0231)
HMT share × Center		0.00783*	-0.0196
		(0.00433)	(0.0225)
HMT share × Northeast		0.0274***	-0.00313
		(0.00766)	(0.0235)
HMT share × Northwest		0.0207	
		(0.0186)	
Foreign share × Southwest		-0.00959	-0.0300**
		(0.00583)	(0.0148)
Foreign share × North		-0.00530*	-0.0238*
		(0.00311)	(0.0141)
Foreign share × East		0.00101	-0.000420
		(0.00660)	(0.0160)
Foreign share × South		-0.0145	-0.0291
		(0.0132)	(0.0191)
Foreign share × Center		0.00903***	-0.0106
		(0.00299)	(0.0139)
Foreign share × Northeast		0.00234	-0.00513
		(0.00675)	(0.0144)
Foreign share × Northwest		0.0118	
		(0.0118)	
Log total industrial output	0.339***	0.225***	0.355***
	(0.0563)	(0.0419)	(0.0474)
Log per capita GDP	0.802*	1.329***	2.061***
	(0.464)	(0.355)	(0.364)
Log per capita GDP square	-0.0444*	-0.0646***	-0.0995***
	(0.0238)	(0.0183)	(0.0188)
Log capital to labor ratio	-0.00633	0.00783	-0.0314
	(0.0285)	(0.0238)	(0.0273)
Share of dirty sectors employment	0.00788***	-0.000938	-0.00223
	(0.00235)	(0.00181)	(0.00211)
HMT share × Level 1	0.0289		0.128***

	(0.0485)		(0.0278)
HMT share × Level 2	-0.00277		-0.00771
	(0.00862)		(0.0270)
HMT share × Level 3	-0.0306***		-0.0138
	(0.0110)		(0.0221)
HMT share × Level 4	-0.00977***		0.0279
	(0.00340)		(0.0220)
Foreign share × Level 1	0.0107		0.0377**
	(0.0210)		(0.0151)
Foreign share × Level 2	-0.0180***		-0.00824
	(0.00510)		(0.0145)
Foreign share × Level 3	-0.0132		0.0125
	(0.0125)		(0.0171)
Foreign share × Level 4	-0.000523		0.0218
	(0.00288)		(0.0135)
Constant	1.058	0.601	-6.467***
	(2.283)	(1.618)	(1.508)
Observations	1,956	1,956	1,870
R-squared	0.934	0.949	0.955
Year FE	YES	YES	YES
City FE	YES	YES	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.2 reports the regression results when I added in the interaction terms between the share of industrial output by each type of firm and city administrative levels and also between firm share and regions. In column 1, I interacted firm share with administrative levels. In column 2, I interacted firm share with regions. In column 3, I included both interactions with administrative levels and interactions with regions.

From column 1, we observe that the coefficients of interactions between HMT share and level 3, HMT share and level 4, and foreign share with level 2 are statistically significant and negative. Specifically, a one percentage point switch of total industrial output from domestic to HMT production in prefecture-level capital cities (level 3) and regular prefecture-level cities

(level 4) cities are associated with a 3% and a 1% decrease of expected industrial sulfur dioxide emissions respectively, keeping all other independent variables constant. A one percentage point switch of total industrial output from domestic to foreign production in sub-provincial-level cities (level 2) is associated with a 1.8% decrease of expected sulfur dioxide emissions, keeping all other independent variables constant.

From column 2, we observe that a one percentage point switch of total industrial output from domestic to HMT production in the South, the Center, and the Northeast are associated with respectively a 5% decrease, a 0.8% increase, and a 2.7% increase of expected industrial sulfur dioxide emissions, holding all other independent variables fixed. Given the geographical proximity of Hong Kong, Macau and Taiwan to Southern China, this result seems to suggest that HMT industrial firms tend to emit less sulfur dioxide nearer to home than in regions further away from home such as central and northeastern China. Besides, a one percentage point switch of industrial output from domestic to foreign production in the North and the Center are associated with a 0.5% decrease and a 0.9% increase of expected industrial sulfur dioxide emissions respectively, keeping all other independent variables constant.

The reason that I included both interactions in column 3 is that both administrative levels and geographical regions might be correlated with industrial sulfur dioxide emissions and also with each other. For instance, it turns out that most sub-provincial level cities in China are located in the Northeast, the East, and the South, all of which are close to the coast. My regressions may therefore suffer from omitted variable bias if I leave out either administrative level or region. Although the correlation between administrative level and geographical region

might result in lower significance levels of the estimates, omitted variable bias would be a more serious problem.

After combining both interactions from column 1 and 2 in column 3, the results changed somewhat. In column 3, we now observe that a one percentage point switch of industrial output from domestic to HMT production in municipalities (level 1) is associated with a 12.8% increase of expected industrial sulfur dioxide emissions, keeping all other independent variables constant. This large magnitude is a little surprising, but this is probably related to the types of industry that HMT firms are associated with in municipalities. In addition, a one percentage point switch of industrial output from domestic to foreign production in municipalities (level 1) is associated with a 3.8% increase of expected industrial sulfur dioxide emissions, keeping all other independent variables constant. In other words, we find that both HMT and foreign industrial firms are associated with higher sulfur dioxide emission levels than domestic industrial firms in municipalities. This suggests the possibility that both HMT and foreign firms have made municipalities their pollution havens and emitted more there. Another possibility is that domestic, HMT, and foreign firms may have been subjected to different regulatory stringency; domestic firms may have been monitored more closely by local governments than the other two groups of firms, giving rise to the gaps between domestic firms and the other two groups.

Moreover, across regions with the Northwest as the reference group in column 3, we again find HMT industrial firms tend to emit less sulfur dioxide in the South in a statistically significant manner. The increase in expected industrial sulfur dioxide emission with a percentage point switch of industrial output from domestic to HMT production is 7.2% lower in the South than in the Northwest, holding other variables fixed. The sensitivity to the environment that

HMT firms demonstrate in southern China may be because HMT firms are careful not to pollute near their home regions or may be related to the types of industry that HMT firms are associated with in southern China. In comparison, foreign industrial firms are correlated with statistically significant lower sulfur dioxide emissions in the Southwest and the North. The increase in expected industrial sulfur dioxide emission with a percentage point switch of industrial output from domestic to foreign production is 3% and 2.4% lower respectively in the Southwest and the North than in the Northwest, holding other variables fixed.

Possibly due to the correlation between administrative levels and cities, fewer coefficients in this regression turned out to be significant. Therefore, we cannot conclude that at lower level cities or in other regions HMT firms and foreign firms are indeed not different from domestic firms in industrial sulfur dioxide emissions. Nonetheless, across all three columns in Table 4.2, the control variables total industrial output, per capita GDP, and per capita GDP squared are statistically significant. The positive and significant relationship between total industrial output and industrial sulfur dioxide supports the scale effect. That means we can expect higher industrial sulfur dioxide emissions as total industrial output increases, holding other variables constant. The positive and significant coefficient of per capita GDP and the negative and significant coefficient of its squared term support the technique effect and suggest an inverted U-shaped relationship between per capita income and industrial sulfur dioxide emissions, consistent with the Environmental Kuznets Curve. This result suggests that sulfur dioxide emissions increase first as per capita income increases but then decreases as income further grows, possibly reflecting people's demand for cleaner environment and for the use of cleaner technologies when their wealth level grows.

6. Conclusion remarks

Different from previous literature, this study represents a first attempt to investigate whether industrial firms of the three types of ownerships differ in industrial sulfur dioxide emissions across city administrative levels and geographical regions in China. With a dataset of 287 cities from 2003 to 2010, I find that industrial firms of different ownerships tend to have different sulfur dioxide emission levels at different city administrative levels and in different regions. In particular, both HMT and foreign industrial firms are associated with higher sulfur dioxide emissions than domestic firms in the four municipality-level cities, supporting a pollution haven story in those cities. Therefore, China's local governments, especially the municipality ones, need to exercise more discretion and judgment when bringing in either HMT or foreign industrial firms to avoid becoming pollution havens of multinational firms. Potentially local governments need to have a longer term view of local economic development and not to lose sight of sound environmental practices. Besides, I also find that HMT firms emit significantly lower levels of industrial sulfur dioxide in Southern China, where Hong Kong, Macau, and Taiwan are closest to geographically. This may reflect HMT firms' desire to not to spill over any pollution back home because of proximity of the south to their home regions. This may as well be due to the type of industry that HMT firms tend to be associated with in southern China. Unfortunately the dataset I use does not break down sulfur dioxide emissions by sector nor does it report output of each type of firm by sector. If data allows in the future, I will also look into the issue of regulations to add another dimension to my analysis. Future research with more refined data should be able to extend this study further and explore the topic more fruitfully.

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