Industrial Activity and the Environment in China:
An Industry-Level Analysis

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Abstract

Given China's rapid industrial expansion a detailed understanding of the linkages through which industrial activity affects the environment is crucial if the resultant environmental impact is to be minimised. This paper utilises a dataset of Chinese industry specific emissions for a variety of pollutants between 1997 and 2003 to provide the first study of its kind for China. For instance, we find an industry's emissions to be a positive function of its energy use and human capital intensity and a negative function of its productivity and R&D expenditure. We also investigate the role played by environmental regulations, both formal and informal.

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Key words: Chinese manufacturing; air pollution; environmental regulations.

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1. INTRODUCTION

In recent years, the rapid industrial growth of China has placed increased pressure on the country's natural environment. With economic growth rates consistently above 8% since 2000 (World Bank 2007), there is a pressing need to find ways to minimise the resultant environmental impact. This impact is already evident. Seventeen of the 25 most polluted cities in the world can be found in China. In terms of global warming, China is likely to be the world's largest emitter of carbon dioxide by 2009-10 when it surpasses the emissions of the USA; and an estimated 300,0000 people die prematurely each year as a result of air pollution (Wang 2007). If future economic growth is to be 'greener' in nature, policymakers require a detailed understanding of the complex linkages between industrial activity, environmental regulations and pollution emissions.

To date, studies examining such linkages at the firm or industry level have often focused on developed economies. For example, Kahn (1999) and Gray and Shadbegian (1995), (2002), (2003) and (2004) examine the relationship between emissions, abatement activity and production levels using US plant and industry level data.[1] Similarly, Cole *et al.* (2005) use industry level data for the UK to identify the determinants of pollution emissions and the extent to which regional characteristics may influence regulations and, in turn, emissions. The minority of firm or industry studies to have examined developing economies include Pargal and Wheeler (1996) who undertake a plant level study of the determinants of water pollution in Indonesia and Dasgupta *et al.* (1999) who examine the effect of regulation and plant-level management policies on environmental compliance in Mexico. As far as we are aware, studies specifically examining the determinants of firm or industry level emissions in China are non-existent, although both Dasgupta *et al.* (2001)

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[1] Earlier US micro-level studies include Bartik (1988), Levinson (1996), Henderson (1996).

and Wang *et al.* (2003) examine the factors that influence firms' compliance with environmental standards.

The aim of this paper is to identify the industrial characteristics that determine industry level emissions intensity in China, thereby providing a greater understanding of the linkages between industrial characteristics, environmental regulations and pollution intensity. Following Pargal and Wheeler (1996) and Cole *et al.* (2005), we work within a framework of the demand for, and supply of, environmental services. The characteristics of an industry determine its demand for such services, whilst society, through environmental regulations, supplies environmental services at a price. The equilibrium level of emissions for a given industry will therefore reflect both demand and supply-side considerations. This provides us with a theoretical framework to explore the possible determinants of industry specific emissions intensity.

The paper makes the following contributions. First, we examine the extent to which an industry's use of factor inputs influences its emissions intensity. Specifically, we assess whether Chinese pollution intensive industries are typically more or less intensive in the use of physical and human capital. Several studies have suggested a positive link between physical capital and pollution intensity in US and UK industries (Antweiler *et al.* 2001 and Cole *et al.* 2005), but this has never been demonstrated for a developing or newly industrialised economy. We also assess whether a firm's productivity levels extend to resource efficiency and hence pollution intensity; whether the size of the average firm within an industry affects pollution; and whether R&D expenditure and the age of plant and machinery within an industry affect pollution intensity. Our analysis enables us to compare the relative magnitude of these effects and the extent to which they vary across different pollutants.

Second, we investigate the role of Chinese regulations. Following Gianessi *et al.* (1979), Pargal and Wheeler (1996) and Cole *et al.* (2005) we argue that there may be both a formal and an informal component to regional regulation levels. We define formal regulations as those that operate through national government or local authorities. In contrast to formal regulations, informal regulations may occur when communities regulate firms or industries through lobbying and petitioning. This may arise due to a perception that formal regulations are weak or absent.[2]

The remainder of the paper is organised as follows: Section 2 provides some background information on the Chinese economy and natural environment; Section 3 discusses the determinants of pollution while Section 4 outlines the econometric specification including data considerations; Section 5 provides our results while Section 6 concludes.

2. BACKGROUND TO THE CHINESE ECONOMY AND NATURAL ENVIRONMENT

Despite average annual industrial value added growth rates in excess of 16% over the period 1997-2004, Figure 1 illustrates that emissions of dust, soot and sulphur dioxide (SO_2), actually fell for at least part of this period.[3] However, SO_2 and soot appear to have

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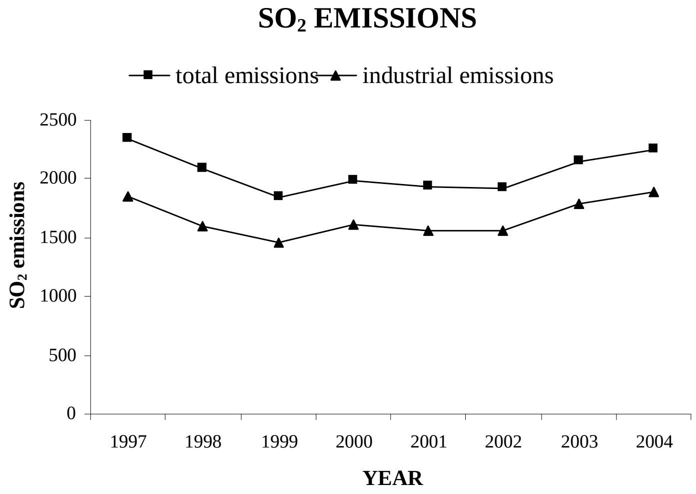
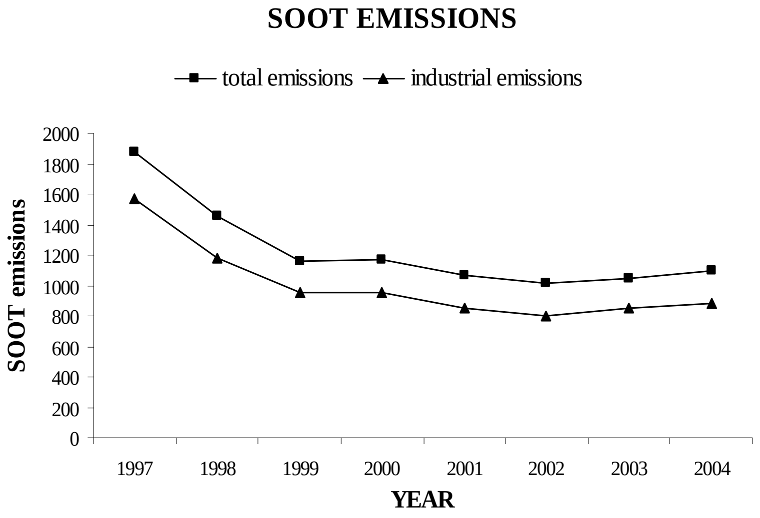
[2] Pargal and Wheeler (1996) investigate the role of informal regulations in plant level emissions of water pollution in Indonesia. They find water pollution to be an increasing function of output and state ownership and a decreasing function of productivity and local (informal) environmental regulations. Whilst interesting, Pargal and Wheeler's study differs from ours in that it examines a single pollutant for a developing country using cross-sectional data only. Nevertheless, some interesting commonalities are found between our results and those of Pargal and Wheeler.

[3] Value added data from China Industrial Yearbook 1997-2004. Data on total dust emissions are not available. Sulphur dioxide emissions refer to the volume of sulphur dioxide emitted by industrial production processes. Soot emissions refer to the volume of particulates in smoke emitted in the process

increased since around the year 2002. Nevertheless, in the face of such economic growth rates the absence of rapidly rising pollution levels suggests that Chinese environmental regulations and energy efficiency gains may have proved reasonably effective. Figure 2 provides further evidence to support this assertion by illustrating the emissions of our three pollutants in the form of intensities i.e. per unit of value added. All three intensities can be seen to fall over time.

Figure 1. Emissions of Sulphur Dioxide (SO_2), Soot and Dust 1997-2004 (tonnes).





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of fuel burning by industrial activity. Dust emissions refer to the volume of particulates emitted by industrial production processes and suspended in the air for a given period of time.

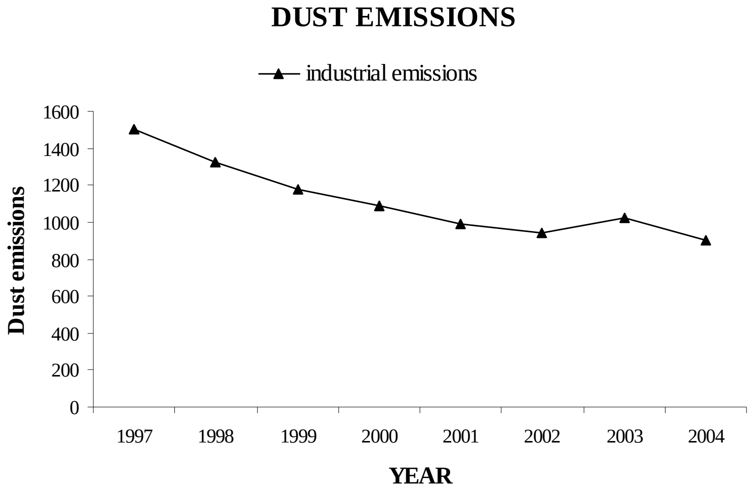
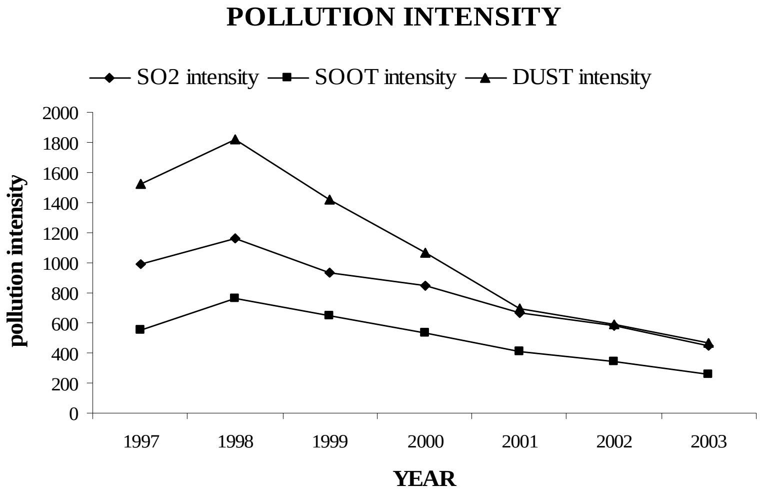


Figure 2: Pollution intensities (tonnes per million yuan of value added) for SO_2*, SOOT and DUST, 1997-2003*



Whilst the aggregate country level trends are interesting, in this paper we are concerned with the examination of pollution patterns at the industry level where we classify industries according to the International Standard of Industrial Classification (ISIC). Due to differences between the ISIC classification and the classification for which Chinese data are reported it proved necessary to aggregate several 3-digit ISIC industries together. The result is that three of our Chinese 'industries' each comprise more than one ISIC industry.[4]

Table 1 presents the average pollution intensities for our three air pollutants for a range of Chinese sectors for period 1997 to 2003. Also provided is each industry's contribution towards total manufacturing value added. In each column the five largest values are highlighted in bold. Considering the value added data first, we see that over the period 1997-2003 the five largest manufacturing industries were Food Beverages and Tobacco, Textiles and Wearing Apparel, Industrial Chemicals, Iron and Steel and Non-Metallic Mineral Products. With regard to the growth of value added, we note that all manufacturing sectors grew rapidly over this period with Iron and Steel, Non-Ferrous Metals, and Machinery Industries growing particularly rapidly.

Turning to the pollution data we see that for all three pollutants the five dirtiest sectors are the same, namely Paper and Products, Industrial Chemicals, Non-Metallic Mineral Products, Iron and Steel and Non-Ferrous Metals. We also note that, of the five dirtiest industries, three are also amongst the five *largest* industries indicating that the composition of Chinese manufacturing is inherently pollution intensive. It can also be seen that two of the dirtiest industries, Iron and Steel and Non-Ferrous Metals, are amongst the five industries that are growing most rapidly.

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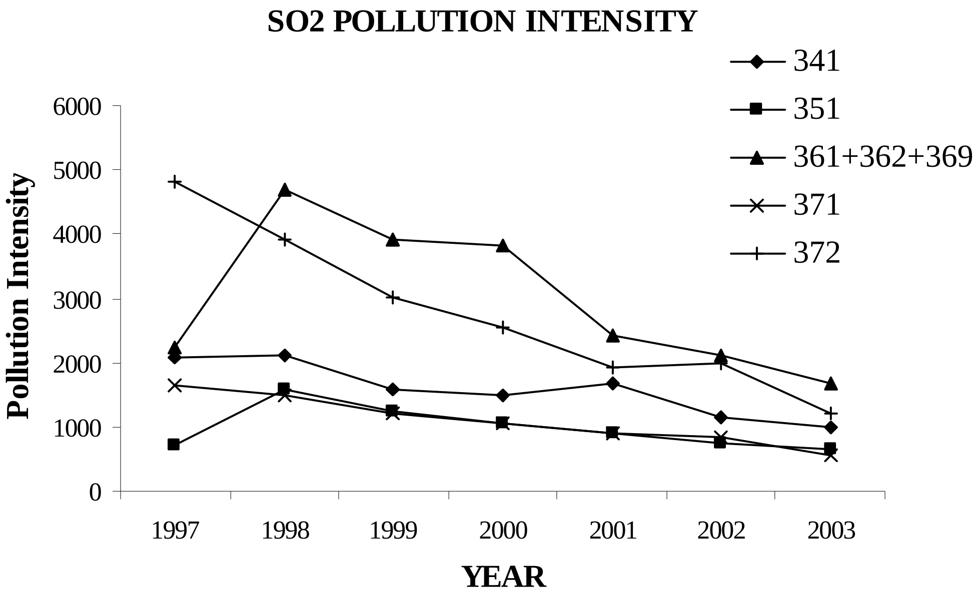
[4] Food, beverage and tobacco consists of ISIC311+313+314, textiles and wearing apparel is ISIC321+322, non-metallic mineral products ISIC361+362+369 and machinery except electrical, electrical machinery, transport equipment, professional and scientific equipment comprise ISIC382+383+384+385.

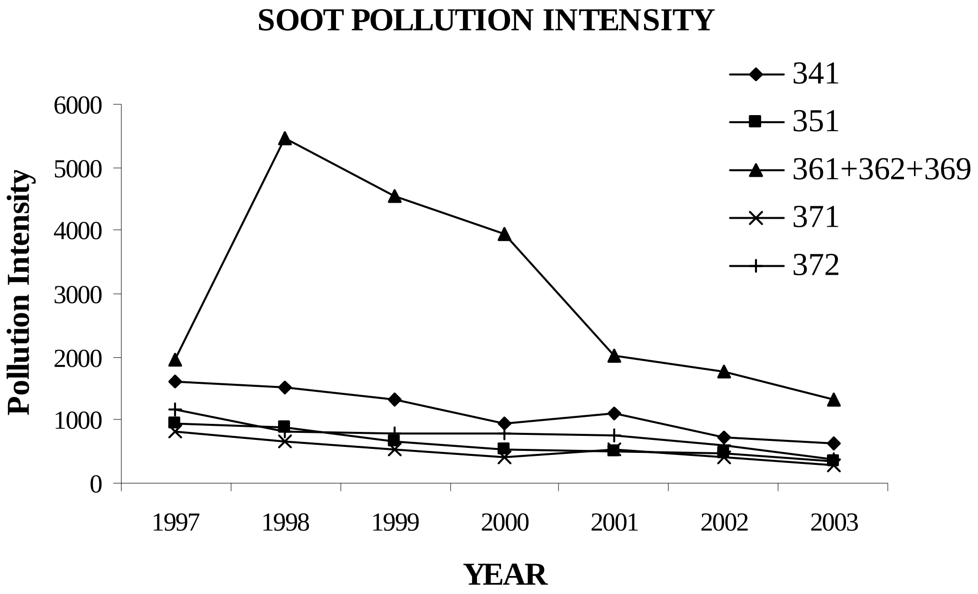
Table 1: Average Pollution Intensities and Share of Total Value Added, 1997-2003

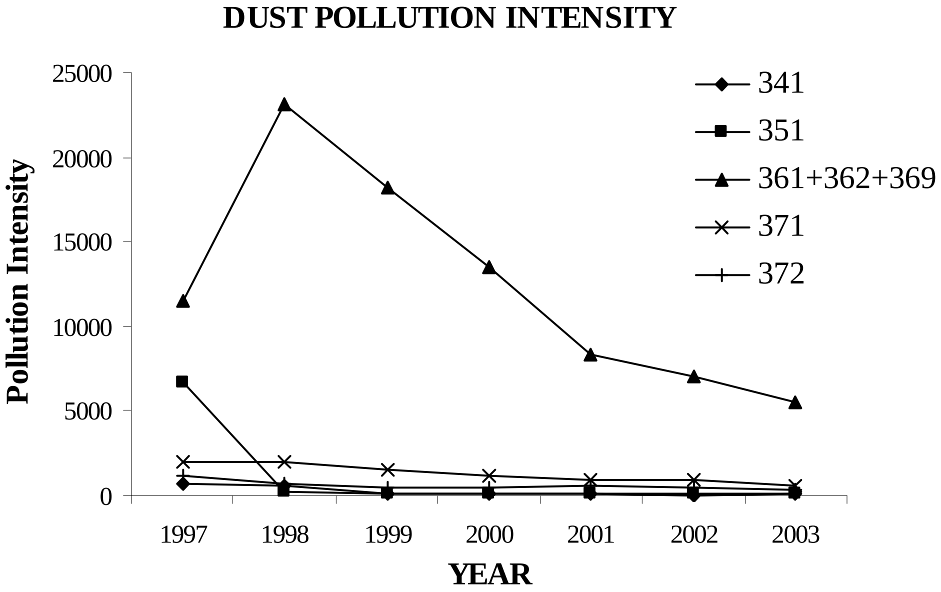
ISIC	Industry	%VA	ΔVA (%)	SO_2	Soot	Dust
311+313 +314	Food, beverage and tobacco	**15.1**	10.8	2.6	2.0	0.1
321+322	Textiles and wearing apparel	**9.6**	9.8	2.7	1.3	0.02
323	Leather products	1.8	11.8	0.9	0.6	0.02
341	Paper and products	2.2	11.3	**15.8**	**11.2**	**2.8**
342	Printing and publishing	1.1	10.4	0.5	0.3	0.05
351	Industrial chemicals	**7.6**	11.5	**9.9**	**6.2**	**10.8**
352	Other chemicals	4.4	**13.6**	4.7	2.3	0.3
353	Petroleum processing and coking	4.0	**13.4**	7.9	5.1	2.1
355	Rubber products	1.2	10.4	4.0	1.6	0.09
356	Plastic products	2.5	13.2	0.6	0.3	0.3
361+362 +369	Non-metallic mineral products	**5.9**	8.2	**29.8**	**30.0**	**124.7**
371	Iron and steel	**7.3**	**17.1**	**11.0**	**5.2**	**13.1**
372	Non-ferrous metals	2.6	**17.4**	**27.9**	**7.6**	**6.0**
381	Metal products	3.3	10.4	1.4	1.0	1.9
382+383 + 384+385	Machinery except electrical; electrical machinery; transport equipment; professional and scientific equipment	31.5	**18.4**	0.8	0.5	0.2

Note: %VA measures each industry's share of total manufacturing value added. ΔVA provides the average annual growth rate of value added over the period 1997-2003. Pollution intensities are measured as tonnes per million yuan of value added. For each column, the industries with the five highest values are highlighted in bold.

Figure 3: Pollution intensity of SO_2, Soot and Dust for the Five Dirtiest Manufacturing Sectors (tonnes per million yuan of value added)







In order to examine industry-specific changes in pollution intensity, figure 3 plots pollution intensity over time for the 5 dirtiest industries for each pollutant. Figure 3 reveals that even the dirtiest Chinese industries have become cleaner over the period 1997-2003 when pollution is measured per unit of value added. Figure 3 also illustrates the differences in pollution intensity across sectors. Non-metallic mineral products (ISIC361+362+369) stand out as the largest polluter but also the sector that has seen the largest fall in its emissions.

3. THE DETERMINANTS OF INDUSTRIAL POLLUTION IN CHINA

To investigate the determinants of pollution we use a 'pollution demand-supply schedule' methodology where emissions are considered as the use of an 'environmental service' and is thus included as an additional input in an industry's production function. Pollution demand is defined as an industry's demand for environmental services; pollution supply is defined as the quantity of pollution that an industry is allowed to emit within a community. The implicit 'price' of pollution is the expected penalty or compensation exacted by the affected community. The greater the pollution generated by industries the higher the costs imposed by the local community. This framework is consistent with that used by Pargal and Wheeler (1996) and Cole *et al.* (2005).

3.1 Pollution Demand

Potentially significant determinants of environmental demand include energy, factor intensities, industry size, production efficiency, equipment vintage and innovation. These factors are briefly discussed below.

Energy use: As previously discussed, it is the high energy-consuming industries that generate the majority of the industrial air pollution within China. The Chinese economy is highly dependent upon the production from heavy industry which tends to require high levels of raw material and energy inputs. Energy use is therefore likely to be a strong positive determinant of industrial air pollution; the more energy intensive production, the greater an industry's demand for pollution.

Factor Intensities: The pollution level of an industry may be influenced by its factor intensities where factor intensities refer to physical and human capital intensity. Several recent studies have suggested that those sectors that face the largest abatement costs per unit of value added also have the greatest physical capital requirements (Antweiler *et al.* 2001 and Cole and Elliott 2003, Cole *et al.* 2005).

In China, anecdotal evidence suggests that those industries that are the most reliant on machinery and equipment generate more pollution than those that rely more heavily on labour. One interpretation is that physical capital intensive industries are also the most energy intensive although there may also be a positive relationship between physical capital use and pollution even after energy use is controlled for (Cole *et al.* 2005).

The link between human capital intensity and industrial emissions is less straight-forward. Cole *et al.* (2005) argue that, on the one hand, high technology, human capital-intensive sectors are likely to be more efficient and less energy intensive and therefore relatively clean compared to lower skilled sectors. On the other hand relatively low skilled, labour-intensive sectors could be fairly clean whilst those industries which typically generate greater volumes of pollution are more likely to be based on complex industrial processes that require higher levels of human capital (skilled labour) to maintain them. Interestingly, Cole *et al.* (2005) find a statistically significant positive relationship between pollution intensity and human capital intensity, suggesting that the latter explanation may be correct at least for developed countries.

Size: Size is measured by the value added per firm in an industry. Pollution intensity is expected to diminish as output increases; moreover, most empirical studies of the relationship between firm size and pollution abatement suggest scale economies in abatement are to be expected, reflecting the benefits of economies of scale both in resource and in pollution abatement. We therefore expect a negative relationship between an industry's gross value added per firm and its pollution intensity.

Efficiency: We might expect an industry that is more productive to be more resource efficient and better managed and hence to be less energy intensive per unit of output. Furthermore, highly productive industries should also be better placed to respond relatively quickly to any change in pollution control incentives. [5]

Vintage: Defined as the use of modern production processes. It is generally expected that a newer plant or one that uses modern production processes will be cleaner. As environmental regulations have become increasingly stringent, modern production processes have become more resource efficient and therefore produce less waste per unit of output. Since China's wide scale economic reforms began in the early 1980s all industries have had increased access to modern production processes and have developed many of the technological capabilities for implementing them throughout their production processes.

Innovation: Innovation within firms, as measured by research and development expenditure, will often result in improvements to the firm's production processes, often resulting in the need for fewer inputs per unit of output. Thus, we might expect innovation expenditure to reduce a firm's demand for pollution.

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[5] Gray and Shadbegian (1995) and Gollop and Roberts (1983), for instance, find that plants with higher levels of abatement costs tend to have lower levels of productivity. However, since plants with high levels of abatement costs would tend to be those from pollution intensive industries, this finding may be driven by the explanation that unproductive industries generate more pollution.

3.2 Pollution Supply

The 'environmental supply schedule' is determined by environmental regulations. Environmental regulations ensure that the greater the use of environmental services (i.e. the larger the emission of pollution) the higher the costs imposed on any firm or industry. Environmental regulations can be defined in terms of formal and informal environmental regulations. In terms of formal regulations, the regulatory authority imposes pollution controls on the community's behalf, e.g. command and control, pollution taxes and tradable permits. Informal regulations are those that act to compensate for weak, weakly enforced or even missing formal regulations. When this is the case, there is now significant evidence to suggest that communities 'informally' regulate polluters themselves through protests, bargaining and lobbying.

Formal environmental regulations have been in place in China for many years. In 1979, the National People's Congress adopted the Environmental Protection Law (EPL), which was officially enacted in 1989. The EPL provides the basic principles governing the prevention of pollution and environmental protection and imposes criminal responsibility for serious environmental pollution. In addition, the pollution levy system was formally introduced by the Chinese government in 1978 with the intention that the levy should be imposed on pollution discharges which exceed national pollution discharge standards. Although the Chinese central government establishes the level and structure of the levy it is the responsibility of local government to collect the levy from firms. Article 16 of Chapter 3 of the EPL states that 'the local people's governments at various levels shall be responsible for the environmental quality of areas under their jurisdiction and shall take measures to improve the quality of the environment' (quoted in Wang *et al.* 2003). As such, local authorities are required to take measures to ensure the air quality in their own jurisdiction meets the prescribed national standard. Not surprisingly, the level of the levy actually paid by firms varies considerably from one region to another and has been shown to be influenced by the level of development (Wang and Wheeler 2000).

There are two main policy strategies on the prevention and control of industrial air pollution in China. The first strategy is to change industry production patterns; the second one is to strengthen the prevention and control of SO_2.

Table 1 has indicated that the composition of the Chinese economy is inherently pollution intensive. Regulators in China thus perceive that changing the structure of the economy can significantly reduce air pollution. The primary source of SO2 and acid rain is coalmines and electricity generation by power stations. A cornerstone of Chinese environmental policy is to close down coal mines with sulphur content more than 3% and small fire power stations with capability less than 50,000 KW (kilowatt). By the end of 1999, such closures contributed to a remarkable and significant reduction in SO2 emission and acid rain. Besides the above source of SO2 and acid rain, other sources include small-scale glass factories, cement factories, and oil refining factories. By shutting down those factories that have a low level of capability, regulators can reduce SO2 emission and acid rain by significant amounts.

The second pollution strategy has been to attempt to limit emissions in designated high-emission areas. These areas are vast and refer to 175 cities over 27 provinces where there is a geographic concentration of population and industry. The areas cover 11.4% of China's surface area and contain sources responsible for 60% of total SO_2 emissions. In the controlled areas, a variety of environmental regulations are implemented to reduce

SO_2 emissions. For instance, a pollution permit scheme is in operation; there are policies to try to encourage the use of cleaner energy sources rather than the traditional reliance on coal; and there is an increase in the standard levy for SO_2 emissions. As a result of these policies air quality within these areas appears to be gradually improving.

Despite formal regulations, a level of informal regulation appears to be present in China. According to the State Environmental Protection Administration there were 51,000 disputes over environmental pollution in 2005. Furthermore, between 2001 and 2005 China's environmental authorities received over 2.53 million letters and 430,000 visits from 597,000 individuals seeking action to mitigate and environmental problem (Wang 2007). There are also numerous anecdotal examples of environmental lobbying proving to be effective. For example, local people repeatedly reported to local officials a smelting plant in western China that was believed to have poisoned hundreds of villagers by dumping lead into the air and water. This lobbying eventually attracted a significant amount of national and even worldwide press attention and ultimately led the environmental protection administration to relocate the plant to a more appropriate area. [6] Secondly, in 2002 there was a proposal to build a large coal-fired power plant in the metropolitan area of Chongqing which was strongly opposed by the public. A newly formed non-governmental organisation, the Green Union of Environment Protection, led the campaign against the construction of the power plant and vociferously lobbied the local government to suspend the project. By the end of 2003 the project was finally cancelled.[7]

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[6] For the full story see ENN "Smelting Plant Blamed for Poisoning Hundreds in China Reported Many Times", September 12, 2006.

[7] Although in these examples the public lobbied the regulators, normally local government, informal regulation may also be 'direct' where the community directly lobbies the firm.

3.3 Pollution Equilibrium

With the above discussion in mind, we define an industry's pollution demand as:

$$e_{it} = f(p_{it}, n_{it}, pci_{it}, hci_{it}, s_{it}, tfp_{it}, vin_{it}, innov_{it}) \qquad (1)$$

where, subscripts i and t denote industry and year, e denotes air emissions, p denotes the expected price of pollution as a result of environmental regulations, n denotes energy use, pci is physical capital intensity, hci is human capital intensity, s is the size of the average firm in the industry, tfp is an industry's total factor productivity, vin is a measure of the vintage of production process and finally $innov$ represents innovation. All variables are defined in the next section.

The expected price of pollution in equation (1) can be identified through the industry's pollution supply schedule. It is in turn a function of the quantity of pollution and the stringency of formal and informal environmental regulations.

$$p_{it} = f(e_{it}, FRegs_{it}, IRegs_{it}) \qquad (2)$$

where p and e are already defined, $FRegs$ refers to formal environmental regulations, whilst $IRegs$ refers to informal regulations.

In equilibrium, substituting p in equation (1) with equation (2) and formulating our pollution function, then we can define emission intensity as:

$$e_{it} = f(n_{it}, pci_{it}, hci_{it}, s_{it}, tfp_{it}, vin_{it}, innov_{it}, F\,\mathrm{Re}\,gs_{it}, I\,\mathrm{Re}\,gs_{it}) \quad (3)$$

4. DATA AND ECONOMETRICS

Our estimating equation originates from equation (3),

$$\begin{aligned} E_{it} &= \alpha_i + \delta_t + \beta_1 N_{it} + \beta_2 PCI_{it} + \beta_3 HCI_{it} + \beta_4 SIZE_{it} + \beta_5 TFP_{it} + \beta_6 CAP_{it} \\ &+ \beta_7 RD_{it} + \lambda REG + \varepsilon_{it} \end{aligned} \quad (4)$$

Our dependent variable, E_{it}, is pollution emission intensity measured as pollution emission per unit of value added. We estimate equation (4) separately for three different sorts of air pollution, namely SO_2, Soot and Dust. The variable a_i with subscript i denotes industry specific effects whilst δ_t with subscript t denotes year specific effects. Equation (4) is estimated for 15 three-digit ISIC manufacturing industries, and the period covers 7 years from 1997 to 2003. All monetary variables are deflated to 1990 prices by a GDP deflator.

4.1 'Demand' Variable Considerations

With regard to our 'demand' variables, N_{it} denotes total energy consumption per unit of value added, including consumption of coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas and electricity. PCI_{it}, physical capital intensity, is measured as non-wage value added per worker. HCI_{it}, human capital intensity, is defined as an average wage paid to staff. Our size variable, $SIZE_{it}$, is defined as value added per firm, calculated as the ratio of an industry's value added to the number of enterprises in that industry. The variable total factor productivity, TFP_{it}, is estimated using a Cobb-Douglas production function.[8] The variable CAP_{it} is an industry's capital expenditure scaled by value added, and we measure the capital expenditure using data on investment in capital construction reported in the China Statistical Yearbook.[9] Under the assumption that the greater such investment within an industry, the newer the industry's equipment and machinery is likely to be, such investment can act as a good measure for the vintage of production processes. The variable RD_{it} is an industry's research and development expenditure scaled by value added. RD_{it} is measured as investment in innovation, including innovation investment in new construction projects, expansion projects and reconstruction projects within an industry.[10]

4.2 'Supply' Variable Considerations

REG in equation (4) denotes a vector of variables capturing formal and informal regulations. Since direct measures of regulations are not available, we argue that these variables are locally determined and hence capture regulations by using their regional determinants.

Since formal regulation is weak or even absent in developing countries like China, many communities have struck bargains for pollution abatement with local factories. Without recourse to legal enforcement of existing regulations (if any), they must rely on the

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[8] Details regarding our estimation of *TFP* are available upon request. The coefficient on *TFP* in equation (4) is robust to a number of alternative specifications of production functions.

[9] Capital construction refers to the new construction projects or extension projects, and related work of the enterprises, institutions or administrative units, only covering projects with a total investment of 500,000 RMB yuan and over. The purpose of capital construction is mainly for expanding production capacity or improving project efficiency.

[10] Investment in innovation refers to the renewal of fixed assets and technologies innovation of the original facilities in enterprises and institutions. It also includes investment in the corresponding supplementary projects and the related work. This measure only covers projects with a total investment of 500,000 RMB yuan and over.

leverage provided by social pressure on workers and managers, adverse publicity, the threat (or use) of violence, recourse to civil law, and pressure through politicians, local administrators, or religious leaders. This process is distinct from national or local formal regulation in that it uses other channels to induce compliance with community-determined standards of acceptable performance.

Also, *formal* regulation is likely to have a regional component. As already outlined, China's legislation on the prevention and control of air pollution endows local authorities with the power to establish their own standards for those items that are not specified by national standards. Local policymakers can take into account local conditions when implementing environmental policy.

With the above arguments in mind, we need to investigate the local determinants of formal and informal regulations. Our first attempt to capture formal regulations is to use a measure of regional pollution prosecutions, defined as the number of pollution related prosections in a region scaled by a region's industry output.

Since the emphasis placed on formal regulations by local authorities may depend upon the social problems within a region, a region's unemployment rate is included to reflect the social status of that region. The unemployment rate might affect local pollution regulations for two reasons. First, a high unemployment rate in a region might attract more attention from the local authorities and force them to devote more resources to dealing with unemployment hence devoting fewer resources to pollution control. Second, communities in a region may tolerate the existence of a polluting plant nearby if it provides employment. Such an effect is more likely to occur in regions with a high level of unemployment. Both arguments suggest that a region with a high unemployment rate will tend to have lax environmental regulations and attract more pollution intensive industries.[11]

With regard to informal regulation, we postulate that these are also likely to be determined by regional characteristics. There is likely to be a positive link between a region's income and the stringency of its regulations (Dasgupta *et al.* 1995). An affluent neighbourhood might be more concerned about the impact of pollution on property prices than a relatively poor neighbourhood. Similarly, a neighbourhood with a greater proportion of professional workers might be more able to mobilise opposition to pollution intensive plants. We rely upon the unemployment rate to capture wealth, although we do use per capita income in our sensitivity analysis.[12]

Furthermore, regional environmental regulations may be a function of a region's population density. On the one hand, a densely populated area may have more people adversely affected by pollution and hence opposition to a pollution intensive plant may be greater. On the other hand, within a densely populated area a pollution intensive plant may be less 'visible' and hence less likely to come to local people's attention. Our estimation will examine which of these competing effects is dominant.

There are a number of other factors that may determine regional regulations, including demographic factors such as a region's age structure and the population's level of education. Demographic factors may influence the extent to which a region lobbies for cleaner industries, for instance, a younger population may be expected to be more concerned about pollution issues and better placed to lobby against polluters. We

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[11] Deily and Gray (1991) provide evidence that the stringency of environmental regulation faced by US steel mills is a function of local economic conditions.

[12] Since regional formal and regional informal regulations are likely to be driven by the same determinants (e.g. wealth) we are unable to separate these two components.

measure a population's age structure in terms of the number of people under the age of 15.

The level of education in a region may also play a role in determining regional regulations. Communities that consist of people with a low level of education and with little ability to acquire information may give an inappropriately low weight to pollution matters simply because they are not aware of the consequences. Moreover, people in such communities may be incapable of using the available regulatory channels. Hence, polluting plants may locate to areas with a larger percentage of poorly educated people or incumbent firms may simply face less regulatory pressure in areas with below average educational attainment. Our education variable is defined as the share of a region's population that has acquired a college or higher level of education.

In sum, the determinants discussed above for both formal and informal regulations incorporate a region's pollution prosecutions, unemployment rate, population density, age structure, and level of education. As we can see, all of these determinants are region specific. However, our pollution data and industrial characteristic data are industry specific and not region specific. We therefore have to transform our regulation data from region specific to industry specific. To take the example of our pollution prosecutions variable, we do this as follows;

$$REGpros_{it} = \sum_r (s_{irt} * PROS_{rt}) \qquad (5)$$

where subscripts i, r, and t denote industry, region and year, respectively, s is the output of industry i in region r as a share of total national output of industry i, and $PROS_{rt}$ is pollution prosecutions in region *r* scaled by that region's total industry output. Therefore, industries that have a higher share of output in regions with high pollution prosecutions will have higher values of *REGpros*. Equivalent variables for regional unemployment rate, population density, population under the age of 15 and level of education are also calculated in the same way and denoted by *REGunem*, *REGpd*, *REGagapop*, *REGedu*, respectively. These variables are calculated using data for 31 regions in China, including 22 provinces, 5 autonomous districts and 4 municipalities.[13] See Table A1 in the appendix for details on the data.

Endogeneity is a potential problem with some of our regulation variables. The regional unemployment rate, for example, could be endogenously determined by pollution intensity rather than the other way around. It could be argued that high wage individuals will choose not to live in a highly pollution intensive region and hence such a region will have a high percentage of low-income or unemployed individuals. The population density in a region may also be determined by that region's pollution intensity. Individuals would choose not to reside in close proximity to a pollution intensive plant and hence the surrounding population density could be lower. Such endogeneity concerns are examined in our Results section.

Since China's formal environmental regulations are not entirely regional in nature, we rely upon industry effects to capture regulations which are industry specific and which do not change over time and on year dummies to capture effects which are common to all industries but do change over time.

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[13] Hong Kong, Macau and Taiwan are excluded due to lack of data.

Equation (4) is estimated using both fixed and random effects specifications and year dummies are included in all specifications. As outlined previously our prior expectations are as follows: we expect the sign of β_1, the coefficient on energy use per unit of value added and β_2, the coefficient on physical capital intensity, to be positive. The coefficient on human capital intensity, β_3, could be positive or negative depending on whether human capital intensive industries are clean or dirty subject to the industrial features in a particular country; β_4, the coefficient on value added per firm within industry *i* (*SIZE*), β_5 the coefficient on total factor productivity (*TFP*), β_6 the coefficient on capital expenditure (*CAP*) and β_7 the coefficient on R&D expenditure (*RD*), should all be negative. We expect the sign on *REGpros* to be negative and that on *REGunem* to be positive. The sign on *REGpd* may be negative due to the lobbying power of a densely populated region or positive if a plant in a densely populated area is less visible and hence escapes informal regulation. Finally, we expect the signs on *REGagepop* and *REGedu* to both be negative.

5. ESTIMATION RESULTS

5.1 Main Results

We present our main results in Table 2 for both fixed and random effects specifications. The dependent variable is the pollution intensity of SO_2, soot and dust, denoted by SO_2, *SOOT* and *DUST*, respectively. The Hausman specification test rejects the null of consistency when using SO_2 as the dependent variable, but the null cannot be rejected when using *SOOT* or *DUST*. Random effects results may therefore be considered consistent for *SOOT* and *DUST* but greater emphasis should be placed on fixed effects results for SO_2.

Table 2: Determinants of Industrial Pollution (Fixed and Random effects)

	FIXED EFFECTS			RANDOM EFFECTS		
	(1) SO_2	(2) SOOT	(3) DUST	(4) SO_2	(5) SOOT	(6) DUST
Energy	96.43	96.60	542.44	95.21	68.64	327.04
	(2.61)**	(3.29)***	(2.70)***	(3.21)***	(3.93)***	(2.37)**
PCI	0.011	0.0067	0.036	0.0063	0.0088	0.036
	(1.16)	(0.48)	(0.99)	(0.87)	(0.78)	(1.50)
HCI	0.039	0.39	1.59	0.070	0.21	0.74
	(0.24)	(1.86)*	(2.07)**	(0.67)	(1.21)	(1.40)
SIZE	4485.29	1489.81	4282.06	-771.07	-1505.34	-9814.72
	(1.69)*	(0.52)	(0.39)	(-0.43)	(-0.62)	(-1.21)
TFP	-2002.67	-1587.71	-2557.59	-898.19	-1132.91	-3898.71
	(-1.89)*	(-1.54)	(-0.78)	(-1.80)*	(-1.95)*	(-2.15)**
CAP	-1213.19	138.71	-3531.88	-2209.53	-437.46	-7579.95
	(-0.97)	(0.10)	(-0.89)	(-0.98)	(-0.34)	(-1.21)
RD	-106.86	-1463.01	-6797.05	-3112.74	-4149.11	-21487.81
	(-0.07)	(-0.77)	(-1.09)	(-2.21)**	(-2.45)**	(-2.27)**
REGpros	-347.12	-169.92	-845.88	-131.27	-114.75	-870.49
	(-0.95)	(-0.41)	(-0.84)	(-0.42)	(-0.29)	(-0.95)
REGunem	204.47	-110.62	939.041	1054.99	222.73	902.19
	(0.31)	(-0.16)	(0.58)	(1.30)	(0.42)	(0.69)
REGpd	5.91	2.17	-2.42	-0.38	-0.014	-0.86
	(2.29)**	(0.73)	(-0.29)	(-0.57)	(-0.02)	(-0.42)
REGagepop	-51.20	137.88	550.91	84.44	323.89	1926.53
	(-0.12)	(0.31)	(0.42)	(0.23)	(0.84)	(1.46)
REGedu	6061.36	-1247.65	-16783.5	-2067.57	-5340.64	-18514.08
	(1.64)	(-0.39)	(-1.60)	(-0.84)	(-2.42)**	(-2.09)**
R^2	0.604	0.393	0.422	0.588	0.502	0.473
Hausman				140.75	10.97	0.39
(FE.V RE.)				(0.0000)	(0.7547)	(1.0000)
D-M Exog.	0.20	0.61	0.14			
(REGpd)	(0.66)	(0.44)	(0.71)			
D-M Exog.	2.81	0.28	0.70			
(REGunem)	(0.10)	(0.60)	(0.40)			
n	105	105	105	105	105	105

Our dependent variables are expressed in terms of pollution intensities, measured as emissions per unit of value added. t-statistics in parentheses for fixed effects and z-statistics in parentheses for random effects. Time dummies are included. *significant at 10% level; **significant at 5% level; ***significant at 1% level. D-M Exog is the Davidson and Mackinnen test for exogeneity, this test cannot be performed for random effects estimations.

The first point to note is that, across all six models, energy intensity (*Energy*) is a positive and highly significant determinant of pollution intensity. Physical capital intensity (*PCI*) is found to be a positive determinant of pollution intensity across all six models although none of the estimates are significant.

Our estimates of human capital intensity (*HCI*) in Table 2 are consistently positive across all six models and significant in the two fixed effects estimates of *SOOT* and *DUST*. It appears that in China, high skilled, human capital-intensive industries are dirtier than low skilled, labour intensive industries. Contrary to prior expectations, average firm size (*SIZE*) is not a negative, statistically significant determinant of pollution intensity, instead being largely insignificant and of mixed sign. More reassuringly, we find total factor productivity (*TFP*) to be a negative and often significant determinant of pollution intensity. Capital expenditure per unit of value added (*CAP*), our proxy for the vintage of production processes, is found to be a negative determinant of pollution intensity in five of the six models, but is not statistically significant. Finally, R&D expenditure per unit of value added (*RD*) is consistently negative in all six models and significant in all random effects specifications. It suggests that industries that invest in innovation generate less pollution not only in developed countries but also in a developing country such as China.[14]

With regard to our regulation variables, none are consistently significant across all models. That said, *REGpros* and *REGedu* are both consistently negatively signed, in accordance with our prior expectations and *REGunem* is generally positively signed, again in accordance with expectations. *REGpd* and *REGagepop* are of mixed sign. To test for the potential endogeneity of *REGpd* and *REGunem* we perform the Davidson-Mackinnon exogeneity test. The null hypothesis for this test states that OLS estimates would be consistent and hence a rejection of the null suggests that endogenous regressors are having an impact on estimated coefficients and hence instrumental variables should be used. We use lagged values of *REGpd* and *REGunem* as instruments in order to perform

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[14] This finding, to a certain extent, supports the Porter Hypothesis and suggests that while innovation can reduce pollution, the benefits of innovation may partially or more than fully offset the costs of complying with environmental regulations.

the test. As Table 2 indicates, we are unable to reject the null of consistency for either *REGpd* or *REGunem* suggesting that endogeneity is not a problem.

In order to assess and compare the economic significance of our estimated results, Table 3 provides estimated elasticities from the results in Table 2. Of the statistically significant variables, Table 3 suggests that *Energy* and *TFP* have perhaps the largest impact on pollution intensity. Taking the fixed effects SO_2 model as an example, these results suggest that a 1% increase in energy use will lead to a 1.04% increase in SO_2 intensity, while a 1% increase in *TFP* will reduce SO_2 intensity by 3.5%. The magnitude of the *HCI* estimates and some of the regulation variables are also relatively large when statistically significant.

Table 3: Estimated Elasticities from Table 2.

	FIXED EFFECTS			RANDOM EFFECTS		
	(1) SO_2	(2) SOOT	(3) DUST	(4) SO_2	(5) SOOT	(6) DUST
Energy	1.04***	1.60**	4.34***	1.027***	1.19***	2.61***
PCI	0.45	0.44	1.097	0.26	0.58	1.096
HCI	0.24	3.81**	7.12**	0.43	2.078*	3.33
SIZE	0.52*	0.27	0.36	-0.089	-0.28	-0.83
TFP	-3.50*	-4.44*	-3.29	-1.57*	-3.17***	-5.01***
CAP	-0.13	0.024	-0.28	-0.240	-0.076	-0.61
RD	-0.018	-0.40	-0.84	-0.53**	-1.12***	-2.66***
REGpros	-0.51	-0.40	-0.92	-0.19	-0.27	-0.95
REGunem	0.55	-0.47	1.83	2.81	0.95	1.76
REGpd	3.44**	2.024	-1.03	-0.22	-0.013	-0.37
REGagepop	-0.13	0.57	1.043	0.22	1.34	3.65*
REGedu	3.32	-1.094	-6.72	-1.13	-4.69***	-7.41**
R^2	0.604	0.393	0.422	0.588	0.502	0.473
n	105	105	105	105	105	105

*significant at 10% level; **significant at 5% level; ***significant at 1% level.

5.2 Sensitivity Analysis

To check the sensitivity or our results to changes in our specification Table 4 presents a number of robustness checks. For reasons of space we focus on fixed effects results and two of our three pollutants, SO_2 and *SOOT*.[15]

Models (7) and (8) begin our sensitivity analysis by dropping energy use from our standard model. We now find *PCI* becomes statistically significant for SO_2 at least, indicating that physical capital intensive firms are more pollution intensive, *ceteris paribus*, because they tend to be more energy intensive.[16] This accords with prior expectations although it is interesting to note that Cole *et al.* (2005) find physical capital intensity to be significant even once energy use is controlled for, suggesting that physical capital intensive firms are pollution intensive for reasons unrelated to their use of energy.

Models (9) and (10) replace *TFP* with a simpler measure of labour productivity measured as gross output per worker. Although no longer statistically significant, labour productivity is consistently negative as a determinant of pollution intensity, providing some support for our main results in Table 2.

Models (11) and (12) drop all of the regulation variables and reply upon the industry and year effects to capture the effects of environmental policy. The sign and significance of our results remains very similar to those in Table 2, suggesting that the regulation variables are not unduly influencing the coefficients on the non-regulation variables.

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[15] Random effects results and results for *DUST* are available on request.

[16] In unreported fixed effects estimations for *DUST,* and in random effects results, *PCI* also becomes positive and significant once energy use is dropped.

Finally, models (13) and (14) use an alternative measure of regional regulations, namely regional per capita income, a more direct measure of determinant of environmental regulations. In light of endogeneity concerns we again perform Davidson-Mackinnon exogeneity tests which are unable to reject the null of consistency, suggesting endogeneity is not present.[17] Contrary to prior expectations, we find income to be a positive determinant of pollution, significant in the case of SO_2. This suggests that, unlike in a developed economy such as the UK, in China the most affluent regions are also the most pollution intensive since this is where heavy industrial activity is greatest. Indeed, in China a disproportionate share of industrial activity occurs in the coastal regions (Shanghai, Guangdong, Zhejiang, Tianjing and Fujian) and Beijing. These regions are therefore highly attractive to pollution intensive industries such as Iron and Steel and Non-Ferrous Metals and hence we appear to find that affluence and polluting activity goes hand-in-hand, particularly when considering the relatively large regions which we examine in this paper. Ideally, our regions would be much smaller and hence we then might find that, at a micro level, there is in fact a separation of wealth and polluting activity. Unfortunately, a lack of data prevents us from using smaller regions.

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[17] Davidson-Mackinnon test results using lagged *REGpcy* as an instrument are 2.75 (0.11) and 0.11 (0.74) for SO_2 and *SOOT*, respectively.

Table 4: Sensitivity Analysis

FIXED EFFECTS	(7) SO_2	(8) *SOOT*	(9) SO_2	(10) *SOOT*	(11) SO_2	(12) *SOOT*	(13) SO_2	(14) *SOOT*
Energy			116.849	109.13	123.86	97.73	78.93	89.20
			(3.0)***	(3.9)***	(3.0)***	(3.9)***	(2.0)**	(2.9)***
PCI	0.0224	0.0177	0.0143	0.0101	-0.0021	0.00037	0.0037	0.00147
	(1.9)*	(1.2)	(1.0)	(0.6)	(-0.4)	(0.03)	(0.5)	(0.1)
HCI	0.0614	0.411	-0.0192	0.344	0.21	0.46	0.28	0.47
	(0.3)	(1.9)*	(-0.1)	(1.7)	(1.5)	(2.4)**	(1.9)*	(2.5)**
SIZE	2445.81	-468.69	5640.15	2497.78	1442.0	657.61	1693.343	705.36
	(1.0)	(-0.2)	(1.7)*	(0.8)	(0.7)	(0.3)	(0.8)	(0.3)
TFP	-2920.97	-2469.55			-630.74	-1207.70	-1711.963	-1413.098
	(-2.4)**	(-2.3)**			(-1.9)*	(-1.4)	(-1.8)*	(-1.5)
Lab. Prod.			-46.38	-39.27				
			(-1.4)	(-1.0)				
CAP	-35.710	1269.43	-1759.30	-305.16	-1894.53	31.87	-1609.63	86.0
	(-0.04)	(0.9)	(-1.2)	(-0.2)	(-1.1)	(0.03)	(-1.02)	(0.07)
RD	208.15	-1160.51	-1211.16	-2366.86	-1935.71	-1771.04	-1226.22	-1636.26
	(0.1)	(-0.6)	(-0.9)	(-1.2)	(-1.3)	(-1.04)	(-0.8)	(-0.9)
REGpros	-506.20	-322.68	-71.49	45.62				
	(-1.1)	(-0.7)	(-0.2)	(0.1)				
REGunem	-100.81	-403.78	232.13	-77.44				
	(-0.1)	(-0.6)	(0.3)	(-0.1)				
REGpd	8.468	4.627	5.106	1.533				
	(2.8)***	(1.5)	(2.2)**	(0.5)				
REGagepop	-323.17	-123.31	-18.93	162.31				
	(-0.8)	(-0.3)	(-0.05)	(0.4)				
REGedu	7299.50	-58.67	5972.17	-1294.05				
	(1.8)*	(-0.02)	(1.6)	(-0.4)				
REGpcy							1.02	0.19
							(2.3)**	(0.5)
R^2	0.518	0.302	0.587	0.382	0.387	0.406	0.554	0.138
n	105	105	105	105	105	105	105	105

Our dependent variables are expressed in terms of pollution intensities, measured as emissions per unit of value added. t-statistics in parentheses. Time dummies are included. *significant at 10% level; **significant at 5% level; ***significant at 1% level.

6. CONCLUSIONS

This paper has carefully examined the possible factors that may influence industrial pollution emissions in China. Our panel data of 15 industries covering the period 1997-2003 has provided a number of insights into what determines industrial pollution intensity. For three air pollutants, SO_2, Soot and Dust, we have found energy use and human capital intensity to be a positive and generally significant determinants of pollution intensity. On the other hand, pollution intensity turned out to be a negative function of the productivity of an industry and an industry's expenditure on innovation. Other factors such as average firm size, capital expenditure and physical capital intensity did not have statistically significant relationships with pollution intensity.

In our model we have no direct measure for pollution regulations. Instead, we have attempted to capture the effects of regulations using year and industry effects, together with those regional characteristics that are likely to influence the stringency of regulation. Our proxies for informal regulations do not perform particularly well in our model. The majority of our regional characteristic variables have an insignificant effect on pollution intensity except the level of education that has a significant effect on the pollution intensity of Soot and Dust. However, we do find the number of pollution prosecutions and the unemployment rate to have consistently negative and positively coefficients, respectively.

Our results suggest that, for both firms and pollution regulators in China, the most fruitful ways in which to reduce industry pollution are to reduce energy use, to stimulate industrial productivity and to increase research and development expenditure. Tax credits or other incentives to stimulate R&D expenditure may be something Chinese policy makers may wish to emphasise. With regard to productivity, our results indicate that 'environmental productivity', perhaps with associated reductions in environmental compliance costs, is a positive side-effect of traditional productivity gains.

We finish on a note of caution. We see this paper as a first attempt to examine the complex linkages between pollution intensity and industrial characteristics for a large developing country such as China. Inevitably the study would have benefited from a richer dataset with a longer time series, greater industry coverage and smaller regional units to capture regional regulatory effects. In time such data may be forthcoming therefore allowing more sophisticated analyses of even greater benefit Chinese policymakers.

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APPENDIX

Table A1: Data definitions and sources:

Variable	**Definition/Source**
Pollution intensity	Emissions divided by gross value added (tons per million yuan). Source: Industry section, China Statistical Yearbook.
Energy consumption	Total energy consumption per unit of value added, including consumption of coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas and electricity. Source: as above.
Energy	Energy consumption divided by gross value added (10000 tons per 100 million yuan). Source: see individual sources for energy consumption and gross value added.
Gross value added	Gross value added by industry. 100 million yuan (1990 price). Source: Industry section, China Statistical Yearbook.
PCI	Physical capital intensity: Non-wage value added per worker ((VA-total wage)/number of staff). Source: wage and number of staff data from China Labour Statistical Yearbook.
HCI	Human capital intensity: average wage by industry. Source: China Labour Statistical Yearbook.
SIZE	Value added per firm. 100 million yuan (1990 price). Source: as gross value added.
TFP	Total factor productivity. Source: data required to calculate TFP is from Industry section, China Statistical Yearbook.
TFPoutput	Gross output per worker. Source: as above.
CAP	Capital expenditure: investment in capital construction per unit of value added (million yuan of investment per million yuan of value added). Source: as above.
RD	Research and development expenditure: investment in innovation per unit of value added, including innovation investment in new construction projects, expansion projects and reconstruction projects within an industry (million yuan of investment per million yuan of value added). Source: as above.
REGpros	Regional pollution prosecution: administrative penalty case on pollution divided by region's GDP (1990 price). Source: China Environment Yearbook.
REGunem	Regional unemployment rate. Source: China Labour Statistical Yearbook.
REGpd	Regional population density: total population divided by region's area. Source: Population section, China statistical Yearbook; area data from http://www.usacn.com.
REGagepop	Share of population under the age of 15: population under 15 divided region's total population. Source: China Labour Statistical Yearbook.
REGedu	Regional level of education: population having acquired college or higher level of education divided by total population. Source: as above.
K	Physical capital stock: original value of fixed assets. Source: Industry section, China Statistical Yearbook.
L	Total labour force: total number of staff. Source: see above.