# Industrial Characteristics, Environmental Regulations and Air Pollution in a Developing Country: An Analysis of the Chinese Manufacturing Sector

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## Abstract

This paper examines and quantifies the complex linkages between industrial activity, environmental regulations and air pollution in China. We utilize a little used dataset of Chinese industry specific emissions for a variety of pollutants between 1996 and 2003. Our analysis allows us to investigate the role played by different determinants of emissions intensity. We find pollution intensity to be a positive function of physical and human capital intensity. Conversely, we find pollution intensity to be a negative function of the productivity of an industry and the industry's expenditure on capital and R&D. Our results also indicate that regulations, both formal and informal, have been successful in reducing the pollution intensity of Chinese industries.

JEL Classification: O13, L60, Q21, Q25, Q28

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 increasing pressure on the country's environmental infrastructure. Such pressures have led to an increased awareness by policy makers and economists of the need to obtain a comprehensive understanding of the relationship between industrial activity, environmental regulations and pollution. The majority of work in this area has been undertaken for developed countries, primarily the US (see e.g. Kahn 1999 and Gray and Shadbegian 1995, 2002, 2003 and 2004 and Cole *et al.* 2005 for a UK study). With the exception of Pargal and Wheeler (1996) in a study of Indonesia, to the best of our knowledge there have been no similar studies for China or any other developing or newly industrialised country.

The lack of studies outside of the US is largely a consequence of a scarcity of data on pollution emissions at the sub-national level and particularly at the industry or plant level. We have been able to partly address this deficiency by the construction of an industry level panel for China. Although not as detailed as the US and UK datasets our data do enable us to examine industry specific emissions of a number of pollutants for China between 1997 and 2003.

The existing US literature has tended to concentrate on the effect of regulations on plant location, productivity and pollution abatement expenditures, usually for selected industries. Gray and Shadbegian (2003) for example, examine measures of environmental regulatory activity and levels of air and water pollution in the Paper and Pulp industry, finding that emissions are affected both by the benefits from pollution abatement and the characteristics of the people exposed to the pollution. Similarly, Bartik (1988), Levinson (1996) and Henderson (1996), Gray and Shadbegian (2002) examine whether a firm's allocation of production across plants responds to the level of environmental regulation faced by individual plants. [1]

In this paper we concentrate on the determinants of pollution for a number of industries in China and endeavour to provide a greater understanding of the linkages between industrial characteristics, environmental regulations and pollution intensity. Such an analysis permits us to assess the relative importance of each determinant of pollution intensity and will indicate how pollution intensity is likely to be influenced by government policy (environmental or otherwise). Our analysis is set within a framework of the demand for, and supply of, environmental services where 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 reflect both demand and supply-side considerations. This provides us with a theoretical framework to explore the possible determinants of industry specific emissions intensity.

Our dataset allows us to make the following contributions: First, we consider the role played by an industry's factor intensities and assess whether industries that have high physical and human capital-intensities generate more pollution per unit of output. Several studies have suggested a positive link between physical capital and pollution intensity in US industries (Antweiler *et al.* 2001 and Cole and Elliott 2003), but this has never been demonstrated for a developing of newly industrialised economy. We also examine whether the size of the average firm within an industry affects pollution (do large firms benefit from economies of scale and hence emit less per unit of output than smaller firms?); whether more productive firms are more resource efficient and hence less pollution

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[1] In a related literature, Hamilton (1993), Kahn (1999) and Helland and Whitford (2001) provide estimates of the impact of political boundaries, demographics and political activism on the exposure to pollution. One strand of this literature has concentrated on the characteristics of the population affected by pollution, in particular whether ethnic minorities are adversely affected by pollution. The results to date are somewhat mixed once the time the plant was established is taken into account (for further discussion see e.g. Hamilton 1995, Kreisel *et al.* 1996, Arora and Cason 1999 and Jenkins *et al.* 2002).

intensive; and whether levels of innovation and the age of plant and machinery within an industry affect pollution intensity. We are also able to estimate the relative magnitude of these effects and the extent to which they vary across different pollutants.

Second, we investigate the role of Chinese regulations. We argue, following Gianessi *et al.* (1979) and Pargal and Wheeler (1996), that there may be both a formal and an informal component to regional regulation levels with formal regulations defined as those that operate through national government or local authorities. Where formal regulations are weak or perceived to be insufficient however, it is argued that communities may informally regulate firms or industries through lobbying and petitioning. Our results suggest there may be an element of both forms of regulation in operation in China.[2]

The remainder of the paper is organised as follows: Section 2 reviews the literature, Section 3 provides some background information on the Chinese economy; Section 4 discusses the determinants of pollution while Section 5 outlines the econometric specification including data considerations; Section 6 provides our results while Section 7 concludes.

## 2. LITERATURE REVIEW

There is a significant body of work that examines the interaction between industrial activity, pollution and environmental regulations. Certain studies concentrate on the impact of industrial

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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.

activity on pollution while others examine on the effect of formal and informal regulations on pollution.

Gianessi *et al.* (1979) examines industry-specific determinants of air pollution emissions employing regional characteristics to take account of regional differences in the stringency of regulations. The paper begins by describing how to estimate sector-by-sector damages (or benefits) in a geographical area as a result of different types of pollution.

Gray and Shadbegian (2004) examine the determinants of environmental regulatory activity (inspections and enforcement actions) and levels of air and water pollution for US pulp and paper mills, focusing on the benefits to the surrounding population from pollution abatement. In Gray and Shadbegian (2004) the number of inspections and enforcement actions, and the level of air pollution emissions and water pollution discharges, are both regressed as dependent variables, the difference being that the former provides a direct measure of regulatory pressure whilst the latter can be treated as an indirect measure related to regulatory stringency. With regard to the independent variables, they capture the marginal benefits of pollution reduction at a given plant, which depends heavily on the number of people in the area and the emissions that they are exposed to, and also capture differences in people's susceptibility to pollution exposure.

Plant characteristics affecting abatement costs are taken into account in their model as control variables that include plant capacity, plant age, firm financial condition, county attainment status (air only), major source and public health effects (water only), and a measure of state environmental attitudes. The key variables are those that influence the marginal benefits from pollution abatement: the expected benefits of pollution reduction in air and water respectively; groups with greater sensitivity to air pollution (population under the age of 6 and those 65 and over); poor and minority groups (the percentage of the nearby population living below the poverty line and the population that is non-white); voter activity indicating political pressure; and the effects of political boundaries indicating whether the plant is within 50 miles of another jurisdiction.

The results suggest that plants in areas with higher marginal benefits of pollution abatement have lower pollution levels. Demographics also matter, as plants where nearby there are more children, more elderly, and fewer poor people, emit less pollution. Plants whose pollution affects residents of other states emit more pollution, with these boundary effects reduced if bordering states have more pro-environment Congressional delegations. Plants in areas with politically active populations that are also environmentally conscious tend to emit less pollution. However, the percentage of nonwhites near the plant, expected to reduce regulatory attention, is often associated with more regulatory activity and lower emissions.

Other US based studies have tended to concentrate on the effect of environmental regulations on plant location, productivity and pollution abatement expenditures, usually for a small number of selected industries. As indicated in Gianessi *et al.* (1997), policy-makers should evaluate the impact of environmental regulation on an industry-by-industry basis, to avoid substantial under- (or over-) estimates. Gray and Shadbegian, (1995) employ plant-level data from three industries, paper and pulp mills, oil refineries, and steel mills, to similarly investigate the impacts of environmental regulation on productivity. The results show that in a broad sense, plants with high compliance expenditures tend to have lower total factor productivity levels and plants with compliance expenditures tend to have slower productivity growth rates.

In a more detailed study of one industry, Gray and Shadbegian (2003) examine the impacts of environmental regulation on productivity for the Paper and Pulp industry accounting for industrial characteristics such as plant vintage and technology. They focus their study on a panel of 116 pulp and paper mills making the distinction between integrated mills and non-pulping plants as the key technology difference across plants. Whether including the pulping stage results in a significant difference in the pollution abatement costs that in turn affects productivity. The reason for introducing plant vintage can be easily explained. Once a plant is in operation, it is very difficult to change the production process, thus, those plants designed before environmental concerns (older plants) are less productive and might have more difficulty meeting a given environmental standard, leading to higher abatement costs.

Focusing on the location decisions chosen by the new plants of Fortune 500 companies between 1972 and 1978, Bartik (1998) suggests that sizable increases in the stringency of state environmental regulation are unlikely to have a large effect on the location decisions of the average industry. Yet, there remains the possibility that these effects are large for heavily polluting industries. Levinson (1996) introduced a broad range of proxies for environmental standard stringency and found the coefficients of these proxies negative and significant only for the plants of very large firms, which suggests that the branch plants of large firms appear more sensitive to local conditions, including environmental regulations, than do all plants in general. One reason proposed is that large firms may have economies of scale in conducting site searches with individual plants being more footloose than those of independent manufacturers. The conclusion from examining the location choice model industry by industry is that few industries have negative and significant coefficients for the environmental stringency variables. Henderson (1996) investigates the effects of local regulatory effort on ground level ozone air quality and on industrial location. Local regulatory effort varies by annual air quality attainment status and by state attitudes towards the environment. A switch from attainment (less polluted) to non-attainment (polluted) status induces greater regulatory effort in a county, leading to an improvement in air quality, thus, polluting industries tend to relocate over time to areas with a record of staying in attainment, so as to avoid regulatory scrutiny.

Building on the earlier micro-level studies introduced above, Gray and Shadbegian (2002) use plant-level data for the paper and oil industries to look at a firm's allocation of production across its plants in different states, measured by the share of its total production occurring in each state. A firm could change its production shares by opening a new plant, but it could also close one of its plants or vary production levels at its existing plants. The model in Gray and Shadbegian (2002) includes several explanatory variables that are state-specific; these range from state-level regulatory variables to input cost and other factors expected to influence the production decision. Their regulatory stringency variables incorporate the support for environmental legislation in Congress; pollution abatement operating costs divided by total manufacturing shipments to measure pollution abatement intensity; 'Green Policies' index to measure the stringency of state environmental regulations; 'Green Conditions' index to measure environmental problems in each state; the number of members of three conservation groups (Sierra Club, Greenpeace, and National Wildlife Federation) to indicate support for environmental issues among the state's electorate; and the dollars per capita spent on the state's programs for environmental and natural resources.

In addition industry characteristics variables are included such as: a state-specific demand index by industry; a Herfindahl index, measuring how concentrated the production of oil or paper is in the state; oil or paper industry shipments from plants by state to indicate the size of an industry. Factor price measures include the energy price, land price and staff wages; labour indicators include percent of non-agricultural workforce unionised, unemployment rate and income; education levels; tax differences; the percentage of votes for Democratic candidates in the U.S House of Representatives for the state; population density; and the extent of the available market in the state.

The results suggest that, with regard to the industry characteristics variables, higher state demand for an industry's product is associated with greater production in the state; higher energy prices and a dirtier environment are associated with lower production shares; higher income generates high demand for a clean environment and therefore is negatively associated with production shares. With regard to firm compliance and state regulatory stringency they find a significant relationship between regulatory stringency and production allocation for the paper industry. States with stricter regulations have smaller production shares, and the impact of stringency is concentrated on low-compliance firms, where firms with high compliance rates appear to be more likely to produce in more regulatory stringent states. Yet, they find few significant interactions between regulatory stringency and industry characteristics within a state. The overall results are weaker for the oil industry in terms of statistical significance, although the negative impacts of state regulatory on production shares, concentrating among low-compliance firms is consistent with the Paper and Pulp industry.

Other related studies include Hamilton (1993), Kahn (1999) and Helland and Whitford (2001) who provide estimates of the impact of political boundaries, demographics and political activism on the exposure to pollution.

Hamilton (1993) demonstrate that commercial hazardous waste firms took into account the potential for areas to mobilize and engage in collective action in their selection of counties in which to add capacity during the period 1987-1992. An empirical model estimates the probability that capacity expansion will occur in a given location as a function of the location-specific characteristics variables that determine the potential profits for a given area. These characteristics include the current levels of processing capacity and waste generation, factor costs, potential compensation payments, and the ability of residents to use collective action to translate compensation demands and opposition into costs that firms must consider.

Controlling for other location-specific characteristics, the results indicate that the greater the voter turnout in a given area, the less likely that area was to be slated for expansion of commercial waste processing capacity. Furthermore, results from several alternative tests provide evidence that the voter turnout rate is a good proxy for collection action: first, voting rates and firm decisions to close facilities are positively related, i.e., the more politically active the community, the more likely hazardous waste facilities were to plan net reductions in capacity; second, voter turnout rates are statistically insignificant in modelling capacity decisions at onsite generators where public opposition is not often a direct deterrent; third, the significance of voter turnout rates is increasing in modelling current expansion decisions versus past facility location decisions in an era (1970s) of laxer regulatory standards and low public opposition.

Kahn (1999) linked local pollution levels to local manufacturing activity levels in two-digit SIC industries, concentrating on US Rust Belt counties, where increased foreign competition and lower demand for products such as steel led to sharp declines in manufacturing output and employment. The pollution level indicator is ambient total suspended particulates, which is one of the six ambient pollutants regulated under the Clean Air Act. The manufacturing activity indicator is total value shipped, which is a better proxy for measuring production over time than using a county/industry's total employment. There are two empirical models employed, in the first one, local air quality is solely a function of manufacturing activity within a given county's borders; whilst the second one considers whether neighbouring counties' economic activity can reduce the quality of life in bordering counties.

The results thus show that the Rust Belt counties that had a high concentration of primary metals activity experienced significant improvements in environmental quality. The study also found evidence of significant cross-county pollution spillovers, reduced manufacturing activity in one county lowers pollution levels in adjacent counties. In addition, with regard to the 'border' effects, Helland and Whitford (2001) test a jurisdictional model using the Toxic Release Inventory (TRI) data from 1987 to 1996 and found that facilities located in counties bordering other states have significantly higher levels of toxic releases into the air and water. Their releases shipped off-site or stored on land show no systematic significant difference.

Only a few studies are concerned with informal regulations. In addition to Gianessi *et al.* (1979), Pargal and Wheeler (1996) investigate informal regulation on industrial pollution, using evidence from Indonesia. Based on an 'environmental supply/demand schedule', Pargal and Wheeler (1996) investigate the determinants of industrial pollution and include "supply" and "demand" schedule variables. With regard to the former characteristics tested include: income; education; level of civic activity; legal or political recourse; media coverage; presence of a nongovernmental organization; the efficiency of existing formal regulation; and the total pollution load faced by the community. With regard to 'demand schedule', the potential determinants include sector specific, output, manufacturing wage, materials price, capital price, energy price, equipment vintage, efficiency or productivity, and ownership.

Pargal and Wheeler's study combines Indonesian manufacturing and socioeconomic census data and examines industrial pollution with observations on plant-level water pollution. Results suggest that, without any formal regulation, equilibrium emissions vary strongly across firms and regions in response to differences in scale, regional input prices, firm characteristics, and the degree of informal regulation by local communities. Pollution intensity declines with scale, indicating that larger plants are cleaner than smaller ones. Firm and plant characteristics appear to have a strong impact on pollution intensity, plants in the food and paper sectors have the highest pollution intensity, more productive plants are cleaner and older plants are dirtier. Foreign participation does not have a significant effect on pollution intensity. Public ownership, on the other hand, is strongly associated with 'dirty' production. Income and education are strongly consistent with the informal regulation hypothesis, i.e. pollution intensity declines with an increase in community incomes, and also declines with an increase in community share of residents with greater than primary education. Finally, the results for plants' local employment share and population density suggest that the visibility effect is clearly dominant: plants with higher local employment shares have lower pollution intensities, and plants in less densely populated areas are less pollution-intensive.

Cole, Elliott and Shimamoto (2005) use a similar methodology to Pargal and Wheeler (1996) but employ industrial pollution data with observations on air pollution for the UK manufacturing sector. For a wide range of air pollutants, they found pollution intensity to be a positive function of energy use and physical and human capital intensity; a negative function of the size of the average firm in an industry, the productivity of an industry and the industry's expenditure on capital and R&D. The results also indicate that regional population density, unemployment rates, age structures and per capita incomes had an influence on pollution intensities during their sample period. In common with Pargal and Wheeler (1996), pollution is found to be a negative function of per capita incomes, but contrary to their results, a negative function of population density. The interpretation for such difference might be that in Indonesia, plants in rural areas are more visible and are therefore held more accountable than plants in urban areas, whilst in the UK it appears that the lobbying power of a densely population region overwhelms any 'visibility' effect.

In this paper we draw on the methodology employed by Pargal and Wheeler (1996) and Cole *et al.* (2005) to investigate the determinants of industrial pollution in China. Before we outline our methodology and describe the data it is useful to review the background to China's economic development and how environmental regulations have evolved over time.

## 3. BACKGROUND TO THE CHINESE ECONOMY

China's economy has grown remarkably since the 1980s but such growth has had a detrimental effect on China's environment. In this section of the paper we explore the factors that led China to reach such critical levels of industrial pollution.

### *3.1 The Factors Causing Pollution in Chinese Industry*

Industrial pollution is an almost inevitable consequence of economic development. According to the Kuznet's curve literature, industry pollution and economic growth rates are likely to increase simultaneously at the present development stage in China. Current industrial production levels in China rely heavily on the consumption of natural resources and raw materials and as a result have low efficiency in energy utilization. Research in China's Industrial Development Report (2005) suggests that the energy consumption to create one dollar of GDP in China is 4.3 times more than the US and 11.5 times more than Japan. The energy utilization rate in China is only 26.9% of that in US, and 11.5% of that in Japan. The real efficiency of electricity generation by power stations in China is 6~11 percent lower than the international level. If the energy utilization rate in China could reach the level of developed countries, there would be an annual average reduction of 4 million tons in SO2 emission and 40 million tons in total suspended particulate (TSP) emission.[3]

Moreover, the industry pattern in China is inclined towards the production of heavy industry. Even before the recent economic reforms, heavy industry already dominated the national economy. Even though agriculture and light industry have both developed substantially in recent years, heavy industry continues to play a key role in the Chinese economy. The main raw materials used in heavy industry are energy and mine products. Heavy industry also relies on the primary sectors that

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[3] Data source: China's Industrial Development Report 2005.

demand high levels of energy consumption and in turn generate high levels of pollution, these sectors are petroleum, coal, electric power, chemicals and smelting and pressing sectors.

One achievement of Chinese economic reform is a boost in the development of medium- and small-sized enterprises, especially the development of town and township enterprises. However, due to a number of disadvantages faced by these enterprises, for example, low levels of technology, high consumption of energy and raw materials, improper distribution, low-skilled management, and little abatement cost, the growth in the number of medium- and small-sized enterprises has resulted in further damage to China's environment. From January 1996 to December 1997, State Environmental Protection Administration, Ministry of Agriculture, Ministry of Finance, and National Bureau of Statistics jointly organized an inspection on industrial pollution within Chinese town and township enterprises. The outcome revealed that SO2 emissions from town and township enterprises increased by 23% compared to the level in 1989, whilst industrial soot increased by 56% and industrial dust increased by 182%.[4]

Another factor that is having a detrimental effect on pollution levels is the perception that many Chinese firms have a short-term profit motive rather than a policy to maximise long-term economic revenue, which in turn lead them to pursue profit maximization at the cost of the environment. Meanwhile, local government puts more emphasis on industrial production, jobs and revenue and tends to ignore environmental issues, even turning a blind eye to the pollution levels of local firms.

### *3.2 The Status of Industrial Pollution in China*

Industrial pollution now receives the attention of policymakers in China and there have been some resultant improvements. For example, investment on environmental protection is gradually

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[4] Data source: China's Industrial Development Report 2005.

increasing and more stringent regulations are being implemented. Such improvements have, to some extent, resulted in a reduction in the total volume of national pollution. Table 1 displays the emission levels of the main pollutants in China and specifies emissions by industrial source.

Table 1: SO2, Soot, Dust annual emission (10000 tons)

| Year | Total emission | | Annual change | | Industrial emission | | | Annual change | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SO2 | Soot | SO2 | Soot | SO2 | Soot | Dust | SO2 | Soot | Dust |
| 1997 | 2346 | 1873 | | | 1852 | 1565 | 1505 | | | |
| 1998 | 2091.4 | 1455.1 | -10.9 | -28.7 | 1594.4 | 1178.5 | 1321.2 | -13.9 | -24.7 | -12.2 |
| 1999 | 1857.5 | 1159 | -11.2 | -20.3 | 1460.1 | 953.4 | 1175.3 | -8.4 | -19.1 | -11.0 |
| 2000 | 1995.1 | 1165.4 | 7.4 | 0.6 | 1612.5 | 953.3 | 1092 | 10.4 | 0 | -7.1 |
| 2001 | 1947.8 | 1069.8 | -2.4 | -8.2 | 1566.6 | 851.9 | 990.6 | -2.8 | -10.6 | -9.3 |
| 2002 | 1926.6 | 1012.7 | -1.1 | -5.3 | 1562 | 804.2 | 941 | -0.3 | -5.6 | -5 |
| 2003 | 2158.7 | 1048.7 | 12 | 3.5 | 1791.4 | 846.2 | 1021 | 14.7 | 5.2 | 8.5 |
| 2004 | 2255 | 1095 | 4.5 | 4.4 | 1891 | 886 | 905 | 5.6 | 4.7 | -11.4 |

Data source: Annual Environment Report for China. Data of total emission of dust is not available.

As shown in Table 1, between 1997 and 2004, the total volume of emissions for Soot has gradually decreased both in terms of total and industrial emissions. Dust has also decreased in terms of its industrial emissions. Total emissions of SO2 declined from 23.46 million tons in 1997 to 22.55 million tons in 2004, a decrease of 3.9%, although industrial emissions of SO2 increased from 18.52 million tons in 1997 to 18.91 million tons in 2004, an increase of 2.1%. Table 1 indicates that a significant reduction in SO2 emissions other than industrial contributes to the overall reduction in total emissions of SO2. Total emissions of Soot declined from 18.73 million tons in 1997 to 10.95 million tons in 2004, a decrease of 41.5%, in which industrial emission of Soot decreased by 43.4%. The decreasing rate of industrial emissions is higher than that for total emissions. Industrial emissions of Dust declined from 15.05 million tons in 1997 to 9.05 million tons in 2004, a decrease of 39.9%. The broad trends in emissions can be seen in figures 1, 2 and 3.

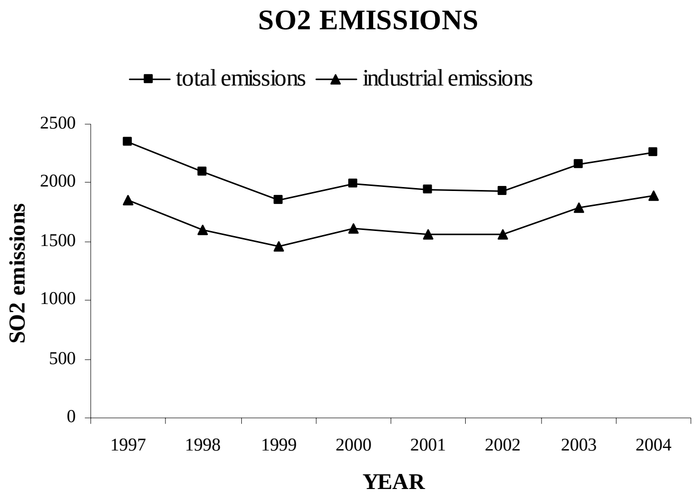

Figure 1: SO2 Emissions (tonnes) 1997-2004

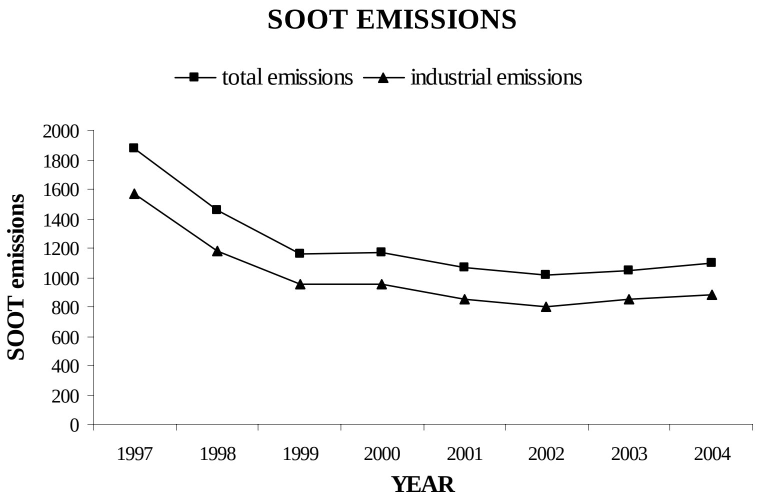

Figure 2: Soot Emissions (tonnes) 1997-2004

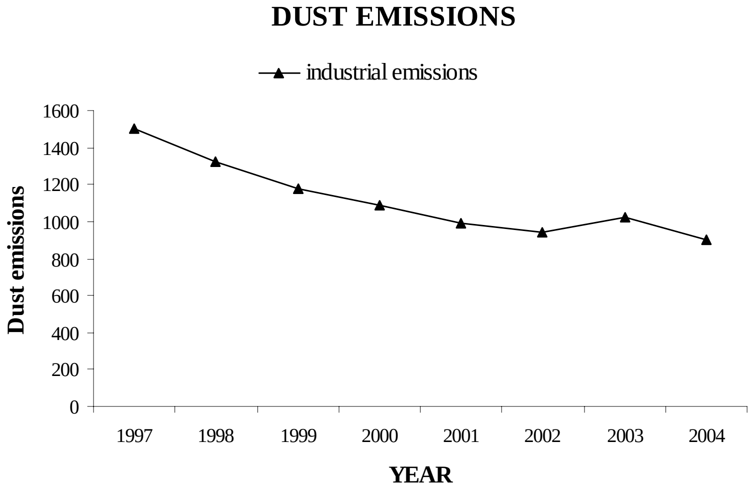

Figure 3: Dust Emissions (tonnes), 1997-2004

Figures 1, 2 and 3 illustrate that although the overall trend is down there appears to be an increase between 2003 and 2004 for SO2 and Soot emissions. Industrial emissions of SO2 increased from 15.62 million tons in 2002 to 17.91 million tons in 2003 rising to 18.91 million tons in 2004. Industrial emissions of Soot increased from 8.04 million tons in 2002 to 8.46 million tons in 2003 and to 8.86 million tons in 2004. Although there is an increase in the emissions of dust from 9.41 million tons in 2002 to 10.21 million tons in 2003, the level dropped significantly to 9.05 million tons in 2004.

One of the most important reasons for the increases in emissions is the rapid growth in the Chinese economy since 2003. In particular there was a rapid growth in those industrial sectors characterized by high levels of energy-consumption and pollution. Consequently, demand for energy and raw materials increased dramatically.

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).

In this paper we have had to aggregate several 3-digit ISIC industries together due to differences between the ISIC classification and the classification for which Chinese data are reported. For example, Food, beverage and tobacco (ISIC311+313+314), Textiles and wearing apparel (ISIC321+322), Non-metallic mineral products (ISIC361+362+369) and Machinery except electrical and machinery electric, transport equipment, professional and scientific equipment (ISIC382+383+384+385). For each industry we also measure that industry's share of total manufacturing value added.

Table 2 presents the average pollution intensities for our three air pollutants for a range of Chinese sectors for period 1997 to 2003.

Table 2: Average Pollution Intensities and Share of Total Value Added, 1997-2003

| ISIC | Industry | %VA | SO2 | Soot | Dust |
|---|---|---|---|---|---|
| 311+313+314 | Food, beverage and tobacco | **15.1** | 2.6 | 2.0 | 0.1 |
| 321+322 | Textiles and wearing apparel | **9.6** | 2.7 | 1.3 | 0.02 |
| 323 | Leather products | 1.8 | 0.9 | 0.6 | 0.02 |
| 341 | Paper and products | 2.2 | **15.8** | **11.2** | **2.8** |
| 342 | Printing and publishing | 1.1 | 0.5 | 0.3 | 0.05 |
| 351 | Industrial chemicals | **7.6** | **9.9** | **6.2** | **10.8** |
| 352 | Other chemicals | 4.4 | 4.7 | 2.3 | 0.3 |
| 353 | Petroleum processing and coking | 4.0 | 7.9 | 5.1 | 2.1 |
| 355 | Rubber products | 1.2 | 4.0 | 1.6 | 0.09 |
| 356 | Plastic products | 2.5 | 0.6 | 0.3 | 0.3 |
| 361+362+369 | Non-metallic mineral products | **5.9** | **29.8** | **30.0** | **124.7** |
| 371 | Iron and steel | **7.3** | **11.0** | **5.2** | **13.1** |
| 372 | Non-ferrous metals | 2.6 | **27.9** | **7.6** | **6.0** |
| 381 | Metal products | 3.3 | 1.4 | 1.0 | 1.9 |
| 382+383+384+385 | Machinery except electrical and machinery electric, transport equipment, professional and scientific equipment | 31.5 | 0.8 | 0.5 | 0.2 |

Note: %VA measures each industry's share of total value added. Pollution intensities are measured as 100 tons per 100 million yuan of value added. For each column, the industries with the five highest values are highlighted in bold.

In Figure 4, pollution intensities for our three pollutants are plotted.

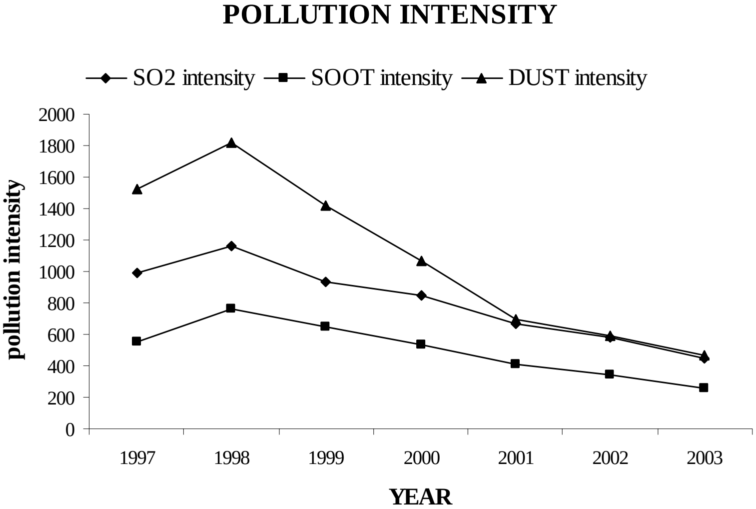

Figure 4: Pollution intensities (100 tons per 100 million yuan of value added) for SO2, SOOT and DUST, 1997-2003

Figure 4 clearly demonstrates that pollution intensity has been decreasing since 1998 for all pollutants. Hence, even though the level of total emissions for SO2 and SOOT rose in 2003, the industrial emissions per unit value added is continued to fall. This suggests that the growth of pollution is accompanied by an even greater growth in industrial production in the Chinese economy.

In Table 2 the five largest values are highlighted in bold. Observe that Paper and products (ISIC341), Industrial chemicals (ISIC351), Non-metallic mineral products (ISIC361+362+369), Iron and steel (ISIC371) and Non-ferrous metals (ISIC372) are consistently amongst the five dirtiest industries across all three air-pollutants.

Figures 5, 6 and 7 plot the pollution intensities of SO2, Soot and Dust for the five dirtiest industries.

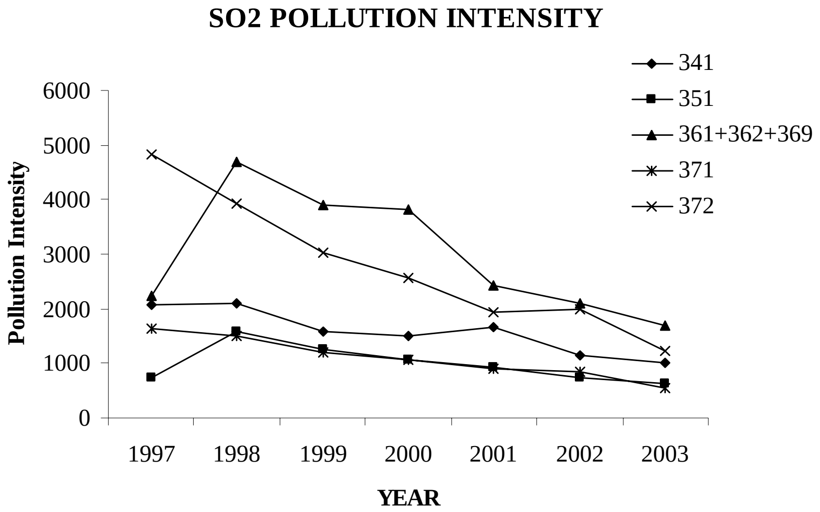

Figure 5: Pollution intensity of SO2 (100 tons per 100 million yuan of value added) for the five dirtiest sectors in China

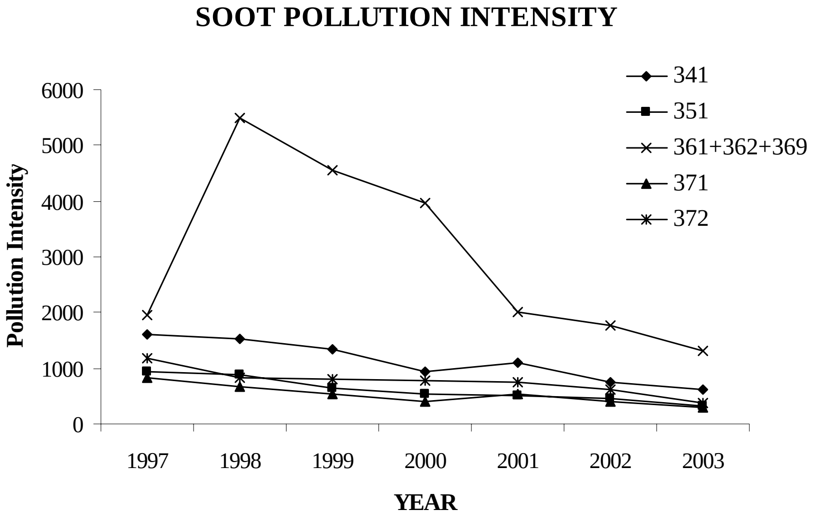

Figure 6: Pollution intensity of Soot (100 tons per 100 million yuan of value added) for the five dirtiest sectors in China

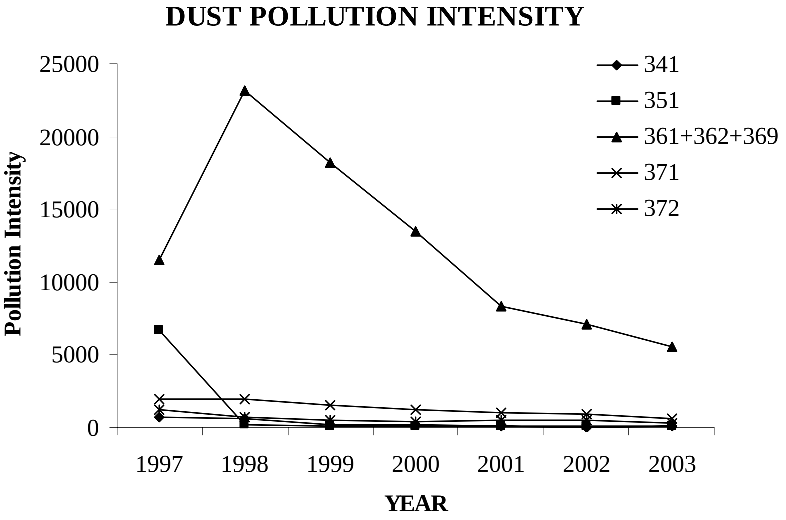

Figure 7: Pollution intensity of Dust (100 tons per 100 million yuan of value added) for the five dirtiest sectors in China

These figures show, that although there is a downward trend across our three pollutants, that there is significant differences in pollution intensities across industries as one might expect. Non-metallic mineral products (ISIC361+362+369) stands out as the largest polluter but also the sector that has seen the largest fall in its emissions.

In the next section we investigate the determinants of industrial pollution in China.

## 4. THE DETERMINANTS OF POLLUTION

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 that refers to the level of emissions that the industry generates. Pollution supply is defined as the quantity that the society is prepared to supply which refers to the amount 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.

### 4.1 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 air pollution in China. The Chinese economy is broadly dependent on the production from heavy industry that 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).

In China, dirty industries, with the higher pollution intensities, tend also to have greater physical capital intensities. The evidence suggests that those industries that are the most reliant on machinery and equipment generate greater pollution than those that rely more heavily on labour. One interpretation is that energy 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, Elliott and Shimamoto 2005).

The link between human capital intensity and industrial emissions is less straight-forward. This ambiguity is explained by Cole, Elliott and Shimamoto (2005) who 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 typically generate greater volumes of pollution are more likely to be based on complex industrial processes that require greater levels of human capital (skilled labour) to maintain them.

*Size*: Size is measured by the value added per firm of the industry. Pollution intensity defined as pollution normalized by gross value added, is expected to diminish as output increases; moreover, most empirical studies of relationship between firm size and pollution abatement suggest scale economies in abatement are the general rule, 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*: Pollution intensity is likely to be a negative function of the efficiency of an industry. We assume that an industry that adopts a high level of technology, whether in production or in management, is more productive. Thus, highly efficient industries are likely to produce less waste per unit of output, *ceteris paribus*. This is evidenced by Chinese industry. In China the utilization efficiency on energy and natural resources is much lower than most other developed countries; likewise, for the level of technology and productivity. Furthermore, highly productive industries should also be better placed to respond relatively quickly to any change in pollution control incentives. It is argued that industries with lower levels of productivity may find it harder to abate pollution emissions and to comply with the requirement of environmental regulations. We therefore expect less productive industries to be more pollution intensive.[5] In our later estimations, we include total factor productivity (*TFP*) as a measure of efficiency.

*Vintage*: also 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 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. Meanwhile, the Chinese government has begun to recognize how serious the

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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.

countries environmental problems are becoming and to take actions to enforce as well as tighten existing environmental regulations on industrial pollution. It is hypothesised therefore that those plants established after the commencement of economic reform in China are expected to be cleaner than plants established prior to the reforms.

*Innovation*: One incentive for a firm to continue to innovate is to promote efficiency. Greater efficiency in production should imply fewer inputs per unit of output, and therefore less resource use intensity. Firms undertake research and development (R&D) to achieve either product or process innovations, the benefit from which is the attainment of greater efficiency. Besides efficiency improvements, process innovations may also provide ways of recycling waste products so that waste is reduced and fewer raw materials are required as inputs. Thus, either promoting efficiency or recycling waste products can lead a firm or industry to save resource and remain clean.[6]

## 4.2 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 emissions 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 government (or local 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. Under these circumstances there is significant evidence to suggest that communities 'informally' regulate polluters themselves through bargaining and lobbying. If local environmental quality fails to meet local

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[6] The Porter hypothesis (Porter and Van der Linde 1995) argues that the cost-saving associated with such process innovations, which may be a response to more stringent regulations, are likely to at least partially offset a firm's environmental compliance costs.

preferences by means of formal regulations then the local community may report the violation of pollution standards to the local authority or pressure regulators and firms to raise standards and improve monitoring and enforcement.

Although formal environmental regulation in China is relatively weak the Chinese government has taken actions to improve matters. The pollution charge system was formally set up by the Chinese government in 1978, claiming that "the levy should be imposed on pollution discharges which exceed national pollution discharge standards, based on quantity and concentration of discharges and levy fee schedules established by the State Council." In 1979, the National People's Congress adopted the Environmental Protection Law (EPL), which was officially enacted in 1989. Regarding formal air pollution regulations, legislation on the prevention and control of air pollution in 2000 specifies that local authorities are responsible for the air quality in their own jurisdictions. As such, local authorities are required to take measures to ensure the air quality in their own jurisdiction meets the prescribed national standard. Whilst the administrative department of environmental protection, under the State Council, establishes national standards for air quality, for those items not specified in the national standards, local authorities have the power to establish local standards of their own and to report to the administrative department of environmental protection.

There are three main policy strategies on the prevention and control of air pollution in China. The first strategy is to change industry production patterns; the second one is to prohibit the production and use of doped fuel nationwide; and the third is to strengthen prevention and control of air pollution in two controlled areas: SO2 and acid rain.[7] Below we consider these strategies in more detail.

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[7] "Two controlled areas" refers to 175 cities over 27 provinces, where there is a geographic concentration of population and well-developed industries. The areas cover 11.4% of the national area and SO2 discharged in this area is 60% of total SO2 discharged nation-wide.

The most important policy for improving air quality is to change industry structure. Most pollution in China is generated as a result of an improper industrial structure. 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 coalmines 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 largest source after industry is road transport. Although the percentage of people that own vehicles in China is not as high as that in most developed countries, the use of doped fuel by most vehicles has caused a significant increase in air pollution.[8] The Chinese government successfully promised that the use of doped fuel would be nationally prohibited by 1st July 2000. Similarly the Chinese Environmental Protection Agency alongside other official organizations launched a project named 'clean vehicle', which refers to the use of vehicles that generate low levels of emissions, for example vehicles using LPG (liquefied petroleum gas) and CNG (compressed natural gas), electric vehicles and some other vehicles employing a high level of technology. The above policies are implemented firstly and most strongly in the two controlled areas since these areas have a geographic concentration of population and well-developed industries. As such, any substantial improvement in these areas can lead to a large change in national environmental conditions.

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[8] 'Doped fuel' is a type of fuel with an additive named tetraethyl lead. The burning of such fuel emits lead and relevant chemical compounds, which can pollute natural environment and directly harm human being's health.

Despite formal regulations, a level of informal regulation appears to be present in China. An example of informal regulation is the petition system. Every year the China Environment Yearbook reports figures indicating the number of people petitioning the national or local authorities to deal with environmental problems by means of writing letters or visiting in person. The system seems to be used by the affected communities. For example, local people repeatedly reported to local officials a smelting plant in western China that poisoned hundreds of villagers by dumping lead into the air and water eventually attracting a significant amount of national and even worldwide press attention that ultimately led the environmental protection administration to relocate the plant.[9] Informal regulation may also be 'direct' where the community directly lobbies the firm.

### 4.3 Pollution Equilibrium

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

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

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.

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[9] ENN FULL STORY, Smelting Plant Blamed for Poisoning Hundreds in China Reported Many Times September 12, 2006

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.

$$p_{it} = f(e_{it}, F\mathrm{Re}gs_{it}, I\mathrm{Re}gs_{it}) \tag{2}$$

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:

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

## 5. ECONOMETRIC SPECIFICATION AND DATA CONSIDERATION

Our estimating equation is based closely on equation (3),

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

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 SO2, Soot and Dust. The variable $a_i$ with subscript *i* denotes industry specific effects whilst $\delta_t$ 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.[10] All related monetary variables are deflated to 1990 prices by a GDP deflator.

## 5.1 '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 in a specific industry. 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 defined in the next section. The variable $CAP_{it}$ is an industry's capital expenditure scaled by value added, and we measure the capital expenditure using the data of investment in capital construction reported in China Statistical Yearbook.[11] 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 consisted of investment in new construction, expansion and reconstruction, 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.[12]

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[10] Although we have data for 2004 for most of our variables, one important variable 'value added' is not reported in the yearbook 2005 and the observable period can only extend to 2003.

[11] 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.

[12] 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.

Total factor productivity, $TFP_{it}$, represents industry efficiency. We expect an industry with high efficiency to be less pollution intensive. Gray and Shadbegian (1995) define the productivity level, $TFP_{it}$, as the residuals from a three-input production function model in which output levels are regressed on three inputs, labour, capital and materials. We use the same methodology but only employ two inputs, labour and capital. Our production function is a Cobb-Douglas production function specified as follows:

$$Y = AK^{\alpha}L^{\beta} \quad \text{where } 0<\alpha<1 \text{ and } 0<\beta<1 \tag{5}$$

*Y* denotes real GDP, *A* represents an index of total factor productivity, *K* denotes the total physical capital stock and *L* denotes the total labour force. We divide equation (5) by the labour force, *L*, to obtain each variable in per worker form:

$$y = Ak^{\alpha}L^{\alpha+\beta-1} \tag{6}$$

where *y* and *k* denote real GDP per worker and the physical capital stock per worker, respectively. Expressing equation (6) in natural logarithms:

$$\ln y = \ln A + \alpha \ln k + (\alpha + \beta - 1)\ln L \tag{7}$$

Our estimating equation is based on equation (7),

$$\ln y_{it} = \phi_i + \varphi_t + \alpha \ln k_{it} + (\alpha + \beta - 1)\ln L_{it} + \varepsilon_{it} \tag{8}$$

where subscripts *i* and *t* denote industry and year, respectively. Our measure of total factor productivity is $(\phi_i + \varphi_t + \varepsilon_{it})$ which is equivalent to *lnA* in equation (7). Equation (8) is estimated for a panel of 15 industries covering the period 1996-2003. Real GDP per worker, $y_{it}$, is an industry's GDP per worker deflated to 1990 prices. We use the original value of fixed assets reported in China Statistical Yearbook as a proxy for physical capital stock, *K*, and the total number of staff of an industry is measured as total labour force, *L*.[13] More information on all data is shown in TableA1 in the appendix. Table 3 provides estimates for both fixed and random effects specifications. Since the Hausman tests can not reject the random effects assumption, it is essential to report estimates from both specifications, so we will have two sorts of $TFP_{it}$ denoted by *TFPfe* and *TFPre* that are separately calculated using fixed effects and random effects estimates.

Table3. Production Function Estimates

| Real GDP per worker (*lny*) | FE. | RE. |
|---|---|---|
| *lnk* | 0.550 | 0.533 |
| | (6.31)*** | (7.77)*** |
| *ln*L | -0.011 | -0.026 |
| | (-0.10) | (-0.32) |
| $R^2$ | 0.983 | 0.770 |
| *n* | 120 | 120 |
| *Hausman (FE V. RE)* | 0.02 (1.00) | |

Note: Time dummies are included. *** and ** denote significance at 99% and 95% confidence levels, respectively.

Using the results shown in Table 3, TFP therefore can be calculated as:

Fixed effects: $$TFP_{it} = \ln y_{it} - 0.55 \ln k_{it} + 0.011 \ln L_{it} \qquad (9)$$

Random effects: $$TFP_{it} = \ln y_{it} - 0.533 \ln k_{it} + 0.026 \ln L_{it} \qquad (10)$$

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[13] The original value of fixed assets refers to the total value of payments on a particular item of fixed asset, including payments on buildings, purchasing, installing, reconstructing, expanding, and payment on technology innovation. In general, it includes value of purchases, cost for packaging, transportation, installation, etc.

The elasticity of output with respect to the physical capital stock $(a)$ is implied by the coefficient of $lnk_{it}$, which is 0.55 subject to the fixed effects specifications and 0.53 subject to the random effects specifications. Since the coefficient of $lnL_{it}$ is $(a+\beta-1)$, the implied elasticity of output with respect to the labour force $(\beta)$ is 0.44 for both effects.

## 5.2 'Supply' Variable Considerations

*REG* in equation (4) denotes a vector of variables capturing formal and informal regulations. All these variables are locally determined rather than using direct measures of formal and informal regulations. Since formal regulation is weak or even absent in developing countries like China, many communities have struck bargains for pollution abatement with local factories, which therefore determines the local characteristics of informal regulations. Communities must often strike bargains about plant-level emissions and risks. Without recourse to legal enforcement of existing regulations (if any), they must rely on the 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 somewhat regional component. As already outlined in China's legislation on the prevention and control of air pollution, it endows local authorities with the power to establish their own standards for those items that are not specified by national standards. What is interesting is that a number of items occur locally but are absent from national legislation, leading local authorities to take a great deal of responsibility for regulating local air pollution. In this case, it is reasonable to assume that formal regulation in China is also closely based on local determinants.

With the above arguments in mind, we need to investigate the local determinants of formal and informal regulations. Note that since both formal and informal regulations are potentially subject to the same regional determinants, we are unable to separate the two effects and therefore have to take both of them into account when considering a particular determinant. The first determinant to capture regional influences on an industry's pollution is a measure of regional pollution prosecutions. In this paper we employ a measure of administrative penalty cases relating to pollution scaled by a region's industry output as a proxy for pollution prosecutions. A region with more administrative penalty cases should be better at enforcing environmental regulations, so we can expect such a region to be more environmentally stringent and thus cleaner.

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.

Regional environmental regulations may also be a function of a region's population density. Population density has two opposite effects on a region's regulations. 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 effect caused by a region's population density is actually dominating in China. We obtain our population density data by taking the ratio of a region's total population to a measure of a region's area.

There are a number of other factors that may determine regional regulations, including demographic factors such as a region's age structure and population's level of education within a region. 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. Cole, Elliott and Shimamoto (2005) employ a share of region's population under the age of 44 as a proxy for younger population. However, such a measure is not readily available for china. Instead we attempt to measure younger population in terms of the population under the age of 15. We acknowledge that this is not ideal to capture the age structure of a region.

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. The variable of education in our estimation is defined as a share of region's population that have acquired a college or higher level of education.

Overall, the determinants discussed above for both formal and informal regulations, incorporate a region's pollution prosecutions (administrative penalty cases), unemployment rate, population density, age structure (a share of region's population under the age of 15), and people's level of education (a share of region's population with college or higher level of education). As we can see, all these determinants are region specific, however, our pollution data and other characteristics data are both industry specific as opposed to region specific, which requires a transformation of our regulation data from region specific to industry specific. Thus we define our pollution prosecution variable as follows:

$$REGpros_{it} = \sum_{r} (s_{irt} * PROS_{rt}) \qquad (11)$$

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 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.[14] See Table A1 in the appendix for details on the data.

Note that $s_{irt}$ is a key variable in equation (11) that needs further explanation. *s* is the output of industry *i* in region *r* as a share of total national output of industry *i*. We have data of gross output (deflated to 1990 prices) by industry for 31 regions in China apart from two regions, Hebei and Gansu. We have only one year (2004) of data for gross output by industry for the latter two regions. Since no more relevant data was available for our observable years (1997-2003), the only channel for obtaining the gross output variable for the two regions is by means of calculation:

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

$$Y_{irt} = \frac{GDP_{rt}}{GDP_{r2004}} \times Y_{ir2004} \tag{12}$$

where $Y_{irt}$ denotes gross output of industry $i$ in region $r$ in year $t$, $GDP_{rt}$ is one region's total gross output in year $t$ and $GDP_{r2004}$ is therefore one region's total gross output in 2004. $Y_{ir2004}$ finally denotes one region's gross output of industry $i$ in 2004. Following equation (12) we calculate the gross output by industry ($Y_{irt}$) for the two regions Hebei and Gansu over our sample period (1997-2003) and in turn gain a value of $s_{irt}$ as a proxy for the real value.

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 is certain to be lower. Moreover, a region's pollution intensity may determine that region's level of education. For example, highly educated individuals are likely to be more aware of detrimental health implications of pollution. Such endogeneity concerns are carefully examined in our sensitivity analysis.

Equation (4) is estimated using both fixed and random effects specifications and year dummies are included in all specifications. We rely on industry specific fixed effects ($\alpha_i$) to capture effects which are specific to each industry but have not changed over time, and year specific fixed effects ($\delta_t$) to capture effects which are common to all industries but have changed over time. As outlined previously our priors are as follows: we expect the sign of $\beta_1$, the coefficient on energy use per unit of value added and $\beta_2$, the coefficient on physical capital intensity, to be positive. The coefficient on human capital intensity, $\beta_3$, 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; $\beta_4$, the coefficient on value added per firm within industry *i* (*SIZE*), $\beta_5$ the coefficient on total factor productivity (*TFP*), $\beta_6$ the coefficient on capital expenditure (*CAP*) and $\beta_7$ 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.

## 6. ESTIMATION RESULTS

### 6.1 Main Results

We present our main results in Table 4 for both fixed and random effects estimates.[15] The dependent variable is defined as pollution intensity for three air pollutants, denoted by SO2emi, Sootemi and Dustemi, respectively.[16] The Hausman specification test rejects the null hypothesis when using SO2emi as dependent variable, but cannot reject it when using Sootemi or Dustemi as the dependent variable. Since the null hypothesis of the Hausman test suggests that the estimator obtained from random effects specification is indeed a consistent and efficient estimator of the true parameters. When considering pollutants Soot and Dust we need to present results for both fixed

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[15] Econometric software STATA 9.0 is applied to run the regressions and the major syntaxes include *xtreg* with *fe* and *re robust*.

[16] Estimations for SO2emi and dustemi use heteroscedastic robust standard errors. However, models fitted on data of sootemi fail to meet the asympototic assumptions of the Hauman test, therefore only providing standard errors without the heteroscedastic robust test.

and random effects specifications and when considering the pollutant SO2 more emphasis should be placed on the fixed effects results.

Table 4: Determinants of Industrial Pollution (Fixed and Random effects)

| | FIXED EFFECTS | | | RANDOM EFFECTS | | |
|---|---|---|---|---|---|---|
| | (1)<br>SO2emi | (2)<br>Sootemi | (3)<br>Dustemi | (4)<br>SO2emi | (5)<br>Sootemi | (6)<br>Dustemi |
| *Energy* | 96.43 | 96.60 | 542.44 | 95.205 | 68.640 | 327.04 |
| | (2.61)** | (3.29)*** | (2.70)*** | (3.21)*** | (3.93)*** | (2.37)** |
| *PCI* | 0.0110 | 0.0067 | 0.036 | 0.00631 | 0.00880 | 0.0363 |
| | (1.16) | (0.48) | (0.99) | (0.87) | (0.78) | (1.50) |
| *HCI* | 0.0385 | 0.389 | 1.585 | 0.0700 | 0.212 | 0.741 |
| | (0.24) | (1.86)* | (2.07)** | (0.67) | (1.21) | (1.40) |
| *SIZE* | 4485.291 | 1489.81 | 4282.06 | -771.07 | -1505.34 | -9814.72 |
| | (1.69)* | (0.52) | (0.39) | (-0.43) | (-0.62) | (-1.21) |
| *TFPfe* | -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 | 138.707 | -3531.88 | -2209.53 | -437.457 | -7579.95 |
| | (-0.97) | (0.10) | (-0.89) | (-0.98) | (-0.34) | (-1.21) |
| *RD* | -106.856 | -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 | -870.491 |
| | (-0.95) | (-0.41) | (-0.84) | (-0.42) | (-0.29) | (-0.95) |
| *REGunem* | 204.472 | -110.62 | 939.041 | 1054.99 | 222.73 | 902.192 |
| | (0.31) | (-0.16) | (0.58) | (1.30) | (0.42) | (0.69) |
| *REGpd* | 5.910 | 2.171 | -2.418 | -0.381 | -0.0137 | -0.861 |
| | (2.29)** | (0.73) | (-0.29) | (-0.57) | (-0.02) | (-0.42) |
| *REGagepop* | -51.20 | 137.88 | 550.906 | 84.444 | 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) |
| *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.

The first point to note is that, across all six models, energy intensity (*Energy*) is a positive and highly significant determinant of pollution intensity and is further evidence that the industrial structure of China is concentrated on energy intensive sectors. 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. In Table A2 in the appendix we drop energy intensity from our estimates given the potentially close relationship between an industry's energy intensity and its physical capital intensity (assuming that capital intensive industries consume a significant amount of energy during the production process). When 'energy intensity (*Energy*)' is dropped from our model we find that *PCI* is positive and significant in four of our six models. This suggests that 'energy intensity' is also capturing a 'physical capital intensity' effect.

Our estimates of human capital intensity (*HCI*) in Table 4 are consistently positive across all six models and significant in two of the fixed effects specifications when the pollution intensity of Soot and Dust are our dependent variables. It appears that in China, high skilled, human capital-intensive industries are dirtier than low skilled, labour intensive industries. To investigate further, Table A3 in the appendix takes our fifteen industrial sectors and selects seven of the most polluted industries and ranks in descending order subject to their pollution intensity for three air pollutants and the average wage for the seven sectors that have the greatest average wage. Of the top seven sectors, five sectors Petroleum processing and coking (ISIC353), Iron and steel (ISIC371), Non-ferrous metals (ISIC372), Other chemicals (ISIC352) and Industrial chemicals (ISIC351), are also included in the seven most polluted sectors in terms of SO2 intensity, Soot intensity or Dust intensity. This suggests that mostly high skilled, human capital intensive industries are also the most pollution intensive industries in China and is consistent with our regression results.

Within the fixed effects specifications, for all of our three air pollutants, pollution intensity turns out to be a positive function of the average size of a firm in an industry (*SIZE*) and significant for SO2. However, size was negative (although insignificant) across all random effects specifications. To investigate further we examined the three industries that have the largest size of average firm from our fifteen industries, Petroleum processing and coking (ISIC353), Iron and steel (ISIC371) and Other chemicals (ISIC352), and three industries that have the smallest size of average firm, Printing and publishing (ISC342), Plastic products (ISIC356), and Fabricated metal products (ISIC381).[17] Figure 8 plots the pollution intensity of SO2 for the six selected industries.

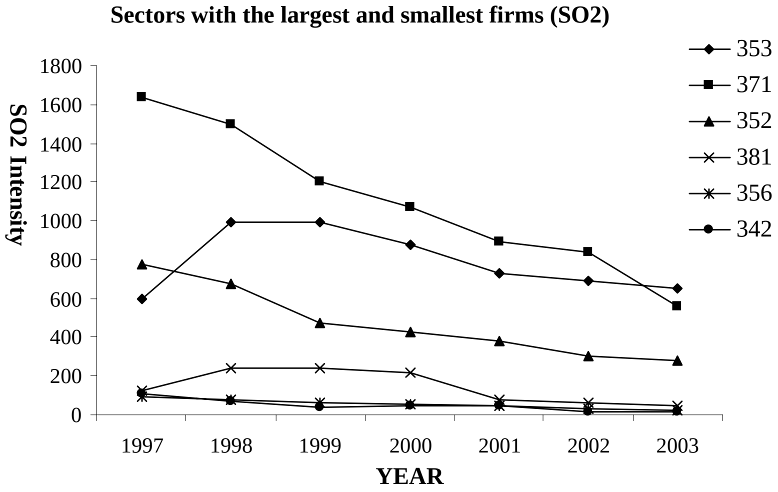

Figure 8: SO2 intensity for the sectors with the largest and the smallest firm size

Note that the pollution intensity of SO2 and its size rankings are closely matched. Figure 9 and 10 plot the pollution intensity of Soot and Dust, respectively.

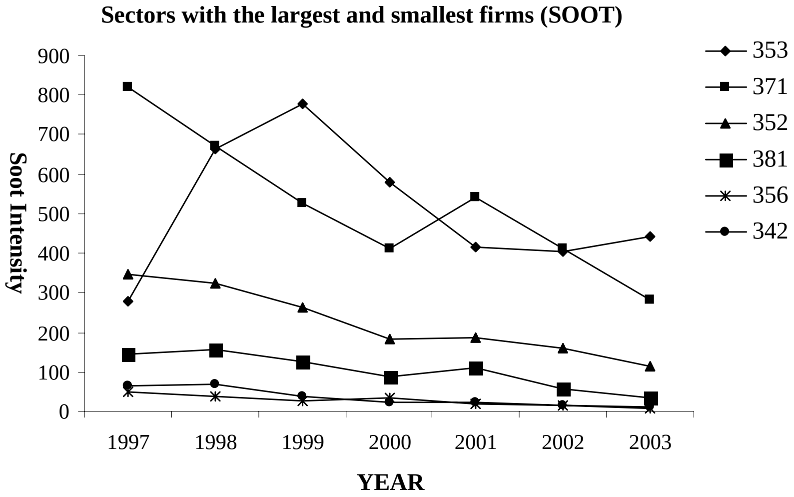

Figure 9: Soot intensity for the sectors with the largest and the smallest firm size

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[17] The selection of industries is based on the data calculated by averaging size variable over year for each industry.

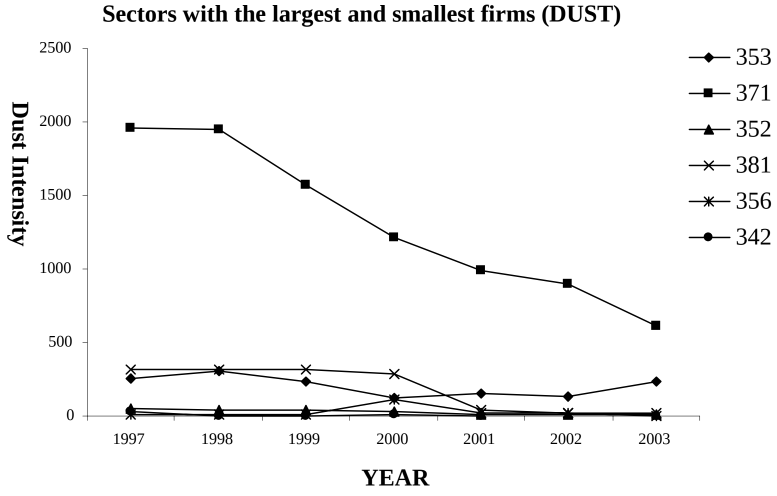

Figure 10: Dust intensity for the sectors with the largest and the smallest firm size

Although the rankings of pollution intensity and size of average firm in Figure 9 and 10 are not as closely matched as those in Figure 8, it is still clear that industries that have firms of the largest size have high pollution intensities while industries that have firms of the smallest size have lower levels of pollution intensity relative to those large firm sized industries. Our Chinese data thus indicates that the pollution intensity of an industry is positively influenced by the size of average firm of that industry, particularly for the industries emitting a great level of SO2. Thus, there does not appear to be an economics of scale effect on average firm size.

Returning to Table 4, we find total factor productivity (*TFPfe*) to be a negative and often significant determinant of pollution intensity. Since the hypothesis in the Hausman specification test is earlier tested and not rejected, we need to report TFP estimated both from fixed and random effects specifications. Our main results in Table 4 employ TFP regressed using fixed effects specification.[18]

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[18] We also estimated table 4 using TFP calculated using random effects. The sign and significance on all the variables of interest were similar.

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, and yet is not found to be statistically significant across all models. 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 like UK but also in developing countries like China.[19]

With regard to our regulation variables, our pollution prosecution variable, *REGpros*, is consistently negatively signed across all models, although not significant throughout. Our study employs administrative penalty cases as a proxy for pollution prosecution and to some extent the results provide evidence that the greater an industry's concentration in regions with a great number of administrative penalty cases relating to pollution (relative to region's industry output) the lower its pollution intensity.

The estimated coefficient on regional population density (*REGpd*) is positive in model (1) and (2), and negative in model (3) to (6). For our three air pollutants, regional population density only significantly influences the pollution intensity of SO2 in the fixed effects specification. This suggests that industries intensively distributed in densely populated areas have higher levels of pollution intensity of SO2. To investigate further, figure 11 displays averaged population density for all regions in China.

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[19] 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.

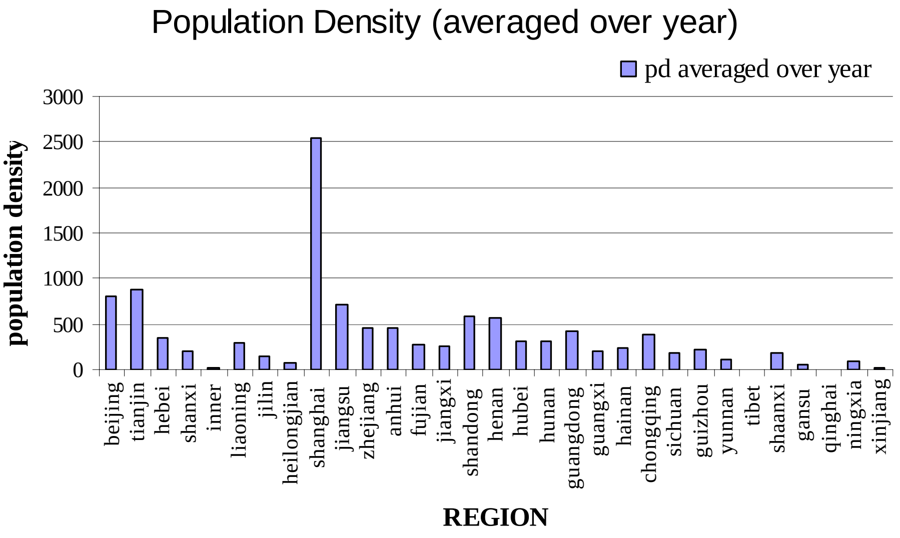

Figure 11: Population density for 31 regions in China

Note that the ten regions with the greatest population density (Shanghai, Tianjin, Beijing, Jiangsu, Shandong, Henan, Zhejiang, Anhui, Guangdong and Chongqing) tend to cover the geographical areas where inward direct investment tends to locate. Furthermore, regions with high population densities are almost all within the 'SO2 controlled area' where the majority of SO2 pollution is generated and the Chinese government has placed the most emphasis on the control for SO2 emissions. Thus, for China there appears to be a positive relationship between regional population density and pollution intensity, but only for SO2.

The estimated coefficient on regional unemployment rate (*REGunem*) is positively signed across all models except the fixed effects specification for Soot. Although none of estimates for regional unemployment rate are significant, the consistently positive sign suggests that the greater an industry's concentration in regions with many social problems and perhaps therefore less stringent environmental regulations, the higher pollution intensity of this industry.

*REGagepop*, the regulation variable capturing the effects of young population, is found to be positive in the majority of our models, but insignificant. Finally, *REGedu*, which captures regional effects of a highly educated population, negatively determines the pollution intensity in five of our six models and is significant for Soot and Dust in the random effects specifications. This suggests a highly educated population does act to implement informal regulations such that regions with a large highly educated population will be cleaner.[20]

### 6.2 Sensitivity Analysis

To check the sensitivity or our results to changes in our specification we present a number of robustness checks. To test the robustness of our *PCI*, *HCI* and *TFP* variables we test a number of alternative measures of *PCI*, *HCI* and *TFP*. The aim of our sensitivity analysis is to account for possible endogeneity. We focus on testing the endogeneity of our regional regulation variables in order to examine whether the regulation variables are likely to influence our non-regulation variables.

Model (13) to (18) in Table A4 test an alternative measure of *PCI*. Our original measure of *PCI* is defined as non-wage value added per worker (see Table A1). *PCIasset*, is simply measured as an industry's deflated original value of fixed assets per worker, which is a more direct measure of physical capital intensity. *PCIasset* is found to be inconsistently signed and insignificant across the specifications whereas the original measure of *PCI* is a consistently positive (but insignificant) determinant of emission intensity. Model (19) to (24) in Table A5 replace our measure of *HCI* with a measure of *HCImanf*, which is defined as an industry's average wage relative to the average manufacturing sector's wage. *HCImanf* is found to be insignificant across all models. Model (25) to (30) in Table A6 replace our measure of total factor productivity (*TFP*) with a simpler measure of

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[20] When we compare the results for our regulation variables for China with those of Cole, Elliott and Shimamoto (2005) for the UK we observe that greater significance for the UK data. One reason might be that UK regions are a lot smaller than Chinese regions. Ideally we would have within province regulation variables such as city, county or village level but the data is not available.

labour productivity, defined as gross output per worker (*TFPoutput*). This variable is still a consistently negative determinant of emission intensity although always insignificant.

In Table 5 we provide the sensitivity of our results to changes in regulation variables employing fixed effects specifications.

Table 5: Sensitivity Analysis (FIXD EFFECTS)

| FIXED EFFECTS | (31) | (32) | (33) | (34) | (35) | (36) | (37) | (38) | (39) |
|---|---|---|---|---|---|---|---|---|---|
| | SO2emi | Sootemi | Dustemi | SO2emi | Sootemi | Dustemi | SO2emi | Sootemi | Dustemi |
| *Energy* | 123.858 | 97.730 | 515.951 | 122.379 | 96.252 | 508.993 | 123.303 | 96.410 | 509.326 |
| | (2.95)*** | (3.91)*** | (2.73)*** | (2.98)*** | (3.81)*** | (2.72)*** | (3.13)*** | (3.79)*** | (2.70)*** |
| *PCI* | -0.00212 | 0.000366 | 0.0204 | -0.000362 | 0.00212 | 0.0285 | 0.00450 | 0.00295 | 0.0306 |
| | (-0.37) | (0.03) | (0.76) | (-0.05) | (0.18) | (0.96) | (0.54) | (0.24) | (0.98) |
| *HCI* | 0.209 | 0.458 | 1.680 | 0.203 | 0.452 | 1.664 | 0.138 | 0.441 | 1.636 |
| | (1.45) | (2.44)** | (2.06)** | (1.41) | (2.39)** | (2.05)** | (0.94) | (2.29)** | (2.02)** |
| *SIZE* | 1441.992 | 657.609 | 3220.517 | 2135.368 | 1350.593 | 6614.106 | 3073.391 | 1510.682 | 6995.388 |
| | (0.67) | (0.28) | (0.32) | (0.83) | (0.50) | (0.62) | (1.12) | (0.55) | (0.64) |
| *TFPfe* | -630.735 | -1207.695 | -2094.003 | -840.916 | -1417.757 | -3137.209 | -1424.333 | -1517.327 | -3372.277 |
| | (-0.89) | (-1.39) | (-0.76) | (-1.14) | (-1.49) | (-1.04) | (-1.53) | (-1.52) | (-1.04) |
| *CAP* | -1894.534 | 31.870 | -3230.145 | -1821.751 | 104.611 | -2857.475 | -1648.212 | 134.228 | -2789.479 |
| | (-1.14) | (0.03) | (-0.83) | (-1.10) | (0.08) | (-0.74) | (-1.07) | (0.11) | (-0.72) |
| *RD* | -1935.71 | -1771.04 | -4380.648 | -1972.797 | -1808.107 | -4606.032 | -2109.224 | -1831.39 | -4654.621 |
| | (-1.27) | (-1.04) | (-0.70) | (-1.32) | (-1.05) | (-0.73) | (-1.50) | (-1.06) | (-0.73) |
| *REGpros* | | | | -209.154 | -209.036 | -1041.708 | -366.821 | -235.944 | -1102.854 |
| | | | | (-0.71) | (-0.55) | (-1.24) | (-1.07) | (-0.60) | (-1.18) |
| *REGunem* | | | | | | | 1058.737 | 180.691 | 431.117 |
| | | | | | | | (1.44) | (0.35) | (0.34) |
| *REGpd* | | | | | | | | | |
| *REGagepop* | | | | | | | | | |
| *REGedu* | | | | | | | | | |
| $R^2$ | 0.506 | 0.385 | 0.402 | 0.508 | 0.387 | 0.406 | 0.538 | 0.388 | 0.406 |
| *n* | 105 | 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.

Table 5: (*Continued*)

| FIXED EFFECTS | (40)<br>SO2emi | (41)<br>Sootemi | (42)<br>Dustemi | (43)<br>SO2emi | (44)<br>Sootemi | (45)<br>Dustemi | (46)<br>SO2emi | (47)<br>Sootemi | (48)<br>Dustemi |
|---|---|---|---|---|---|---|---|---|---|
| *Energy* | 101.028 | 90.309 | 526.761 | 102.320 | 91.388 | 527.44 | 96.429 | 96.600 | 542.443 |
| | (2.61)** | (3.32)*** | (2.70)*** | (2.66)** | (3.29)*** | (2.64)** | (2.61)** | (3.29)*** | (2.70)*** |
| *PCI* | 0.0170 | 0.00637 | 0.0207 | 0.0161 | 0.00566 | 0.0202 | 0.0110 | 0.00672 | 0.0363 |
| | (1.73)* | (0.48) | (0.61) | (1.57) | (0.41) | (0.61) | (1.16) | (0.48) | (0.99) |
| *HCI* | 0.0148 | 0.407 | 1.736 | 0.00205 | 0.396 | 1.729 | 0.0385 | 0.389 | 1.585 |
| | (0.10) | (2.03)** | (2.15)** | (0.01) | (1.92)* | (2.15)** | (0.24) | (1.86)* | (2.07)** |
| *SIZE* | 3726.75 | 1689.626 | 6484.17 | 3684.767 | 1654.588 | 6462.099 | 4485.291 | 1489.81 | 4282.056 |
| | (1.46) | (0.61) | (0.60) | (1.42) | (0.59) | (0.59) | (1.69)* | (0.52) | (0.39) |
| *TFPfe* | -1848.646 | -1633.539 | -3044.091 | -1835.067 | -1622.206 | -3036.905 | -2002.667 | -1587.708 | -2557.589 |
| | (-1.81)* | (-1.61) | (-0.92) | (-1.78)* | (-1.58) | (-0.92) | (-1.89)* | (-1.54) | (-0.78) |
| *CAP* | -1227.308 | 249.507 | -3113.269 | -1331.012 | 162.929 | -3168.012 | -1213.19 | 138.707 | -3531.88 |
| | (-1.00) | (0.19) | (-0.86) | (-1.00) | (0.12) | (-0.80) | (-0.97) | (0.10) | (-0.89) |
| *RD* | -466.508 | -1381.478 | -5946.958 | -473.716 | -1387.494 | -5950.461 | -106.856 | -1463.007 | -6797.046 |
| | (-0.33) | (-0.74) | (-0.96) | (-0.33) | (-0.74) | (-0.96) | (-0.07) | (-0.77) | (-1.09) |
| *REGpros* | -283.684 | -213.174 | -1172.628 | -254.659 | -188.951 | -1157.228 | -347.124 | -169.918 | -845.880 |
| | (-0.84) | (-0.54) | (-1.27) | (-0.70) | (-0.46) | (-1.20) | (-0.95) | (-0.41) | (-0.84) |
| *REGunem* | 234.620 | -45.020 | 1069.668 | 165.605 | -102.619 | 1033.303 | 204.472 | -110.619 | 939.041 |
| | (0.35) | (-0.07) | (0.68) | (0.23) | (-0.15) | (0.63) | (0.31) | (-0.16) | (0.58) |
| *REGpd* | 6.450 | 1.767 | -5.027 | 6.732 | 2.002 | -4.878 | 5.910 | 2.171 | -2.418 |
| | (2.41)** | (0.64) | (-0.62) | (2.54)** | (0.68) | (-0.60) | (2.29)** | (0.73) | (-0.29) |
| *REGagepop* | | | | 122.387 | 102.141 | 64.538 | -51.197 | 137.871 | 550.906 |
| | | | | (0.30) | (0.24) | (0.05) | (-0.12) | (0.31) | (0.42) |
| *REGedu* | | | | | | | 6061.36 | -1247.652 | -16783.5 |
| | | | | | | | (1.64) | (-0.39) | (-1.60) |
| $R^2$ | 0.578 | 0.391 | 0.408 | 0.579 | 0.392 | 0.408 | 0.604 | 0.393 | 0.422 |
| *n* | 105 | 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.

Models (31), (32) and (33) begin by dropping all the regulation variables out of the estimated equation, relying on the industry and year effects to capture the effects of environmental policy. Note that the remaining determinants of pollution intensity without regional regulation effects return almost identical coefficients to those in our main results in Table 4. The models that follow in Table 5 add each regulation variable in turn. Models (34) to (36) firstly incorporate the regulation variable pollution prosecution (*REGpros*) for three air pollutants, respectively. We notice that pollution prosecution is a consistently negative determinant of pollution intensity for three air pollutants and there is no significant change in other determinants. This suggests that the endogeneity of pollution prosecution can be rejected and it can be included as a regulation determinant.

In models (37), (38) and (39) we show that the regional unemployment rate has no significant influence on other variables. The remaining regulation variables, population density (*REGpd*), the share of population under the age of 15 (*REGagepop*) and the level of education (*REGedu*) are added sequentially, *REGpd* in (40) to (42), *REGagepop* in (43) to (45) and *REGedu* in (46) to (48). None of them prove to be significantly influencing other determinants either in sign or in magnitude.[21] Overall, we can conclude that regulation variables are not unduly influencing the sign and significance of non-regulation variables.

Finally, in Table 6 we, models (49) to (54), we replace all regional regulation variables with regional per capita income, an even more direct determinant of environmental regulations.

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[21] This exercise is repeated for the random effects specifications. The results are similar to the fixed effects results in Table 5.

Table 6: Sensitivity Analysis (Fixed and Random Effects)

| | FIXED EFFECTS | | | RANDOM EFFECTS | | |
|---|---|---|---|---|---|---|
| | (49)<br>So2emi | (50)<br>Sootemi | (51)<br>Dustemi | (52)<br>So2emi | (53)<br>Sootemi | (54)<br>Dustemi |
| *Energy* | 78.926 | 89.195 | 546.637 | 83.948 | 61.998 | 296.622 |
| | (2.00)** | (2.93)*** | (2.76)*** | (3.09)*** | (3.45)*** | (2.15)** |
| *PCI* | 0.00370 | 0.00147 | 0.0165 | 0.00629 | 0.00764 | 0.0378 |
| | (0.51) | (0.13) | (0.59) | (1.12) | (0.71) | (1.54) |
| *HCI* | 0.281 | 0.471 | 1.631 | 0.136 | 0.174 | 0.773 |
| | (1.88)* | (2.47)** | (2.01)** | (1.42) | (1.04) | (1.61) |
| *SIZE* | 1693.343 | 705.359 | 3051.211 | -124.878 | -1575.353 | -11924.11 |
| | (0.75) | (0.30) | (0.30) | (-0.09) | (-0.74) | (-1.62) |
| *TFPfe* | -1711.963 | -1413.098 | -1355.344 | -1073.529 | -895.969 | -2472.552 |
| | (-1.77)* | (-1.47) | (-0.43) | (-2.38)** | (-1.52) | (-1.49) |
| *CAP* | -1609.631 | 85.993 | -3425.235 | -2150.828 | -497.835 | -7090.221 |
| | (-1.02) | (0.07) | (-0.89) | (-1.01) | (-0.39) | (-1.16) |
| *RD* | -1226.224 | -1636.258 | -4863.782 | -1625.126 | -3117.453 | -14450.34 |
| | (-0.79) | (-0.94) | (-0.77) | (-1.06) | (-1.85)* | (-1.98)** |
| *REGpcy* | 1.022 | 0.194 | -0.698 | 0.532 | -0.0476 | -0.268 |
| | (2.25)** | (0.50) | (-0.74) | (1.56) | (-0.15) | (-0.33) |
| $R^2$ | 0.554 | 0.138 | 0.404 | 0.350 | 0.329 | 0.328 |
| *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.

Regional per capita income (*REGpcY*) is significant in only one out of six models (model (49)), and such significant coefficient holds a positive sign. This would suggest that industries located in regions with high level of per capita income generate more SO2 emissions per unit of output than regions with low per capita incomes. The finding that regional per capita income is a significant and positive determinant of SO2 intensity is opposite to the finding from Cole, Elliott and Shimamoto (2005) using UK data, which suggests regional per capita income to be a negative, statistically significant determinant of pollution intensity. Figure 12 allows us to investigate why such differences may exist between the UK and China.

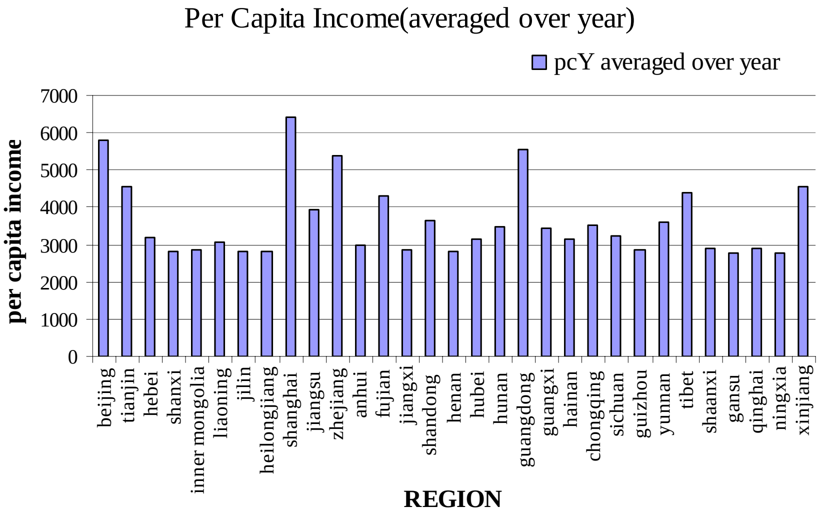

Figure 12: Income per capita for the 31 regions in China

Figure 12 shows that, of the 31 regions in China, there are 8 regions with per capita income RMB4000 yuan or above. Ruling out the 2 regions in the west of China that have very low level of population densities (Tibet and Xingjiang), the remaining regions are mainly coastal regions (Shanghai, Guangdong, Zhejiang, Tianjing and Fujian) and Beijing (the capital of China). Not surprisingly therefore, these regions are the most attractive places for industries to locate and have been the heart of Chinese industrial production since the economic reforms of the early 1980s. Thus, pollution intensive industries like all other industries like to locate in the more developed regions and thus locating based on a range of regional characteristics not just environmental regulation differentials.

### 6.3 Explaining Pollution Changes 1997-2003

Finally, in order to assess the determinants of trends in pollution intensity over our sample period, we examine the extent to which our key explanatory variables are responsible for the change in emission intensity over the period 1997-2003. Using industry means, we use data for 1997 to calculate the predicted value of emission intensity for that year using our estimated results. Then we take emission intensity at 1997 level as a benchmark and compare it with other values of emission intensities that result from changing one of our key explanatory variables. For example, to examine the role played by regional regulations, we replace the original 1997 data of regulations with 2003 data whilst holding non-regulation data (energy intensity, physical and human capital intensity, size, total factor productivity, capital expenditure and R&D expenditure) constant at its 1997 level. This allows us to obtain the predicted value of emission intensity resulted from employing 1997 non-regulation data and 2003 regulation data to see to what extent 1997 emission intensity would have changed if regulations were at their 2003 levels. The same principle is then used to examine the impact of energy intensity (*Energy*), physical capital intensity (*PCI*), human capital intensity (*HCI*) and all other industry characteristics. Table 7 provides the results using both fixed and random effects estimates. Since some values of emission intensity turn out to be negative after we replace 1997 data with 2003 data we drop the negative values out of Table 7 and leave the cells blank, for example, when replacing 1997 data of *REGedu* or *TFP* with 2003 data the emission intensity becomes negative.

Table 7: The Change in Emission Intensity, 1997-2003, resulting from the Change in Environmental regulations, Energy Intensity and Industrial Characteristics (%)

| | FIXED EFFECTS | | | RANDOM EFFECTS | | |
|---|---|---|---|---|---|---|
| | SO2 | SOOT | DUST | SO2 | SOOT | DUST |
| *REGpros* | -15.8 | -11.9 | -23.9 | -6.0 | -9.4 | -24.9 |
| *REGunem* | +50.7 | -42.0 | +144.2 | +263.4 | +99.5 | +140.2 |
| *REGpd* | +217 | +124 | -54.7 | -14.8 | -0.7 | -19.8 |
| *REGagepop* | -0.1 | +0.4 | +0.6 | +0.2 | +1.1 | +2.3 |
| *REGedu* | +184.3 | -58.1 | | -63.3 | | |
| *Energy* | -46.4 | -71.3 | | -46.2 | -59.5 | -98.7 |
| *PCI* | +47.6 | +46.4 | +107.1 | +27.4 | +70.1 | +108.5 |
| *HCI* | +13.7 | +210.3 | +340.1 | +24.2 | +129.8 | +159.2 |
| *SIZE* | +45.2 | +23.0 | +26.8 | -7.8 | -27.4 | -62.1 |
| *TFP* | | | | -61.9 | | |
| *CAP* | -1.1 | +0.2 | -2.0 | -2.0 | -0.7 | -4.4 |
| *R&D* | -0.5 | -9.8 | -18.3 | -13.7 | -32.6 | -58.7 |

Calculated using fixed and random effects results and industry means.

Table 7 indicates, first of all, that the change in regional regulations over the period 1997-2003 had variety of effects on emission intensity depending on the pollutant. The change in regional prosecutions (*REGpros*) had the effect of reducing emission intensity by between 11.9% and 23.9% using the fixed effects outcomes and between 6.0% and 24.9% using the random effects outcomes. The change in regional unemployment (*REGunem*) had the effect of increasing emission intensity by between 50.7% and 263.4%. The effect of changing regional population density (*REGpd*) or regional education level (*REGedu*) is uncertain due to a variety of changes in emission intensity across pollutants. Finally the change in regional age structure (*REGagepop*) had only a small impact on emission intensity.

Table 7 also indicates that changing energy intensity results in a remarkable drop in pollution intensity across all of our three air pollutants using estimates either from fixed effects or random effects estimation. This would suggest that the improvement in energy utilization in China has contributed substantially to the reduction in pollution intensity. On the other hand, our results for changing factor intensities show that neither physical capital intensity nor human capital intensity has had a large impact on reducing pollution intensity. Compared to the pollution intensity at 1997 level, changing factor intensities seems to bring about a higher level of pollution intensity in 2003. Finally, changes in all other four industry characteristics (size, total factor productivity, capital expenditure and R&D expenditure) over the period 1997-2003 results in a variety of effects on emission intensity. Changing industry size (*SIZE*) had no certain effect on emission intensity, the direction of which differs across fixed and random effects specifications. Total factor productivity (*TFP*) had the effect of reducing SO2 intensity by 61.9% under the random effects specification. Changing capital expenditure (*CAP*) and R&D expenditure (*R&D*) both have reduced emission intensity, in which an increase in R&D expenditure had provided a greater drop in emission intensity and the effects are broadly consistent across pollutants.

## 7. CONCLUSIONS

We have carefully examined the possible factors that may have impacted on industrial pollution intensity in China. It is hoped that our results can inform both firms and regulators in seeking a better environment for 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, SO2, Soot and Dust, we have found energy use, and physical and human capital intensity pollution intensity to be a positive determinant of pollution intensity. On the other hand, pollution intensity turned out to be a negative function of the productivity of an industry, the vintage of plants in an industry and an industry's expenditure on innovation. For the size of the average firm in an industry we can only find evidence for SO2, which suggests that the pollution intensity of SO2 is positively determined by the size of the average firm of an industry.

In our model we have no direct measure for pollution regulations. Instead, we have attempted to capture the effects of regulations using those regional characteristics that are likely to influence the stringency of regulation. In China, informal regulations do not perform 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, some regional characteristics are consistently signed such as the number of pollution prosecutions, which is negatively signed and the unemployment rate, which is positively signed.

Our results suggest that, for both firms and pollution regulators in China, the best way to reduce industry pollution is by saving energy since energy use is a highly significant determinant of pollution intensity across all pollutants. One way to influence energy efficiency is for a firm to increase its productivity and thus improve production efficiency. An increase in R&D expenditure will also contribute to industry innovation and thus energy efficiency. Finally, we must remember that China is still developing and as it does so it should demonstrate dramatic improvement in all of the elements discussed above.

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APPENDICES

Table A1: Data definitions and sources:

| **Variable** | **Definition/Source** |
|---|---|
| Pollution intensity | Emissions divided by gross value added (tons per 100 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. |
| *PCIasset* | Original value of fixed assets per worker. Source: Industry section, China Statistical Yearbook. |
| *HCI* | Human capital intensity: average wage by industry. Source: China Labour Statistical Yearbook. |
| *HCImanf* | An industry's average wage relative to the average manufacturing sector's wage. Source: as above. |
| *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 (100 million yuan of investment per 100 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 (100 million yuan of investment per 100 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. |

Table A2: The Determinants of Industrial Pollution with *Energy* dropped (Fixed and Random Effects)

| | FIXED EFFECTS | | | RANDOM EFFECTS | | |
|---|---|---|---|---|---|---|
| | (7) SO2emi | (8) Sootemi | (9) Dustemi | (10) SO2emi | (11) Sootemi | (12) Dustemi |
| *PCI* | 0.0224 | 0.0177 | 0.102 | 0.0178 | 0.0169 | 0.0781 |
| | (1.91)* | (1.22) | (1.96)* | (2.13)** | (1.41) | (2.01)** |
| *HCI* | 0.0614 | 0.411 | 1.696 | 0.118 | 0.231 | 1.201 |
| | (0.32) | (1.85)* | (1.79)* | (0.84) | (1.22) | (1.81)* |
| *SIZE* | 2445.81 | -468.69 | -7207.79 | -978.717 | -964.35 | -8315.22 |
| | (0.98) | (-0.16) | (-0.89) | (-0.51) | (-0.37) | (-1.06) |
| *TFPfe* | -2920.97 | -2469.55 | -7707.56 | -2010.02 | -1937.43 | -7338.11 |
| | (-2.42)** | (-2.32)** | (-1.78)* | (-2.79)*** | (-3.36)*** | (-1.89)* |
| *CAP* | -35.710 | 1269.43 | 3069.02 | 47.084 | 1271.73 | 1157.49 |
| | (-0.04) | (0.91) | (0.64) | (0.03) | (0.95) | (0.27) |
| *RD* | 208.15 | -1160.51 | -4977.10 | -1308.86 | -2716.03 | -11322.74 |
| | (0.13) | (-0.57) | (-1.03) | (-0.87) | (-1.52) | (-1.72)* |
| *REGpros* | -506.20 | -322.68 | -1714.79 | -172.93 | -191.90 | -1257.50 |
| | (-1.13) | (-0.74) | (-1.43) | (-0.51) | (-0.45) | (-1.52) |
| *REGunem* | -100.81 | -403.78 | -774.11 | 1523.56 | 495.03 | 1485.74 |
| | (-0.14) | (-0.57) | (-0.41) | (1.44) | (0.86) | (0.92) |
| *REGpd* | 8.468 | 4.627 | 12.070 | -0.526 | 0.0266 | 0.588 |
| | (2.81)*** | (1.50) | (1.03) | (-0.82) | (0.03) | (0.20) |
| *REGagepop* | -323.17 | -123.31 | -968.28 | -460.28 | -117.39 | -425.54 |
| | (-0.81) | (-0.27) | (-0.75) | (-1.67)* | (-0.30) | (-0.57) |
| *REGedu* | 7299.50 | -58.67 | -10096.64 | -3063.54 | -4962.06 | -18280.78 |
| | (1.76)* | (-0.02) | (-1.11) | (-1.31) | (-2.11)** | (-1.91)* |
| $R^2$ | 0.518 | 0.302 | 0.224 | 0.415 | 0.315 | 0.171 |
| *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.

Table A3: Sector ranking for pollution intensity and average wage.

| Sector Rank | SO2emi | Sootemi | Dustemi | Average wage |
|---|---|---|---|---|
| 1 | 361+362+369 Non-metallic mineral products | 361+362+369 Non-metallic mineral products | 361+362+369 Non-metallic mineral products | 353 Petroleum processing and coking |
| 2 | 372 Non-ferrous metals | 341 Paper and products | 371 Iron and steel | 371 Iron and steel |
| 3 | 341 Paper and products | 372 Non-ferrous metals | 351 Industrial chemicals | 372 Non-ferrous metals |
| 4 | 371 Iron and steel | 351 Industrial chemicals | 372 Non-ferrous metals | 352 Other chemicals |
| 5 | 351 Industrial chemicals | 371 Iron and steel | 341 Paper and products | 382+383+384 +385 Machinery except electrical and machinery electric, Transport equipment, and Professional and scientific equipment |
| 6 | 353 Petroleum processing and coking | 353 Petroleum processing and coking | 353 Petroleum processing and coking | 351 Industrial chemicals |
| 7 | 352 Other chemicals | 352 Other chemicals | 381 Fabricated metal products | 342 Printing and publishing |

Rank is in a descending order. SO2emi, Sootemi and Dustemi respectively denote emissions per unit of value added for SO2, Soot and Dust.

Table A4: Sensitivity Analysis (*PCI* is defined as original value of fixed assets)

| | FIXED EFFECTS | | | RANDOM EFFECTS | | |
|---|---|---|---|---|---|---|
| | (13) SO2emi | (14) Sootemi | (15) Dustemi | (16) SO2emi | (17) Sootemi | (18) Dustemi |
| *Energy* | 98.79 | 91.71 | 576.95 | 97.088 | 72.376 | 345.16 |
| | (2.58)** | (3.21)*** | (2.73)*** | (3.84)*** | (4.31)*** | (2.49)** |
| *PCIasset* | -15.946 | -22.59 | 95.97 | 3.937 | -19.95 | -114.48 |
| | (-0.55) | (-0.49) | (0.76) | (0.18) | (-0.60) | (-1.47) |
| *HCI* | 0.0921 | 0.428 | 1.707 | 0.0993 | 0.204 | 0.611 |
| | (0.57) | (2.12)** | (2.09)** | (0.89) | (1.18) | (1.12) |
| *SIZE* | 4817.01 | 1947.93 | 2445.51 | -2617 | -495.56 | -3549.26 |
| | (1.85)* | (0.65) | (0.21) | (-1.26) | (-0.18) | (-0.43) |
| *TFPfe* | -1683.90 | -1425.16 | -1190.89 | -753.14 | -947.85 | -3295.34 |
| | (-1.77)* | (-1.52) | (-0.38) | (-2.01)** | (-1.94)* | (-2.11)** |
| *CAP* | -1668.76 | -342.54 | -2640.66 | -2342.35 | -731.83 | -8753.48 |
| | (-1.19) | (-0.23) | (-0.59) | (-0.99) | (-0.54) | (-1.37) |
| *RD* | -676.59 | -1843.55 | -8296.25 | -3844.49 | -4489.06 | -23394.53 |
| | (-0.45) | (-1.03) | (-1.26) | (-2.38)** | (-2.67)*** | (-2.32)** |
| *REGpros* | -236.79 | -78.38 | -800.09 | 85.564 | 14.299 | -263.38 |
| | (-0.67) | (-0.19) | (-0.76) | (0.32) | (0.04) | (-0.27) |
| *REGunem* | 193.52 | -126.89 | 1009.58 | 1304.48 | 246.33 | 1279.30 |
| | (0.30) | (-0.19) | (0.64) | (1.55) | (0.46) | (0.99) |
| *REGpd* | 5.156 | 1.704 | -4.879 | -0.857 | -0.255 | -1.990 |
| | (2.33)** | (0.60) | (-0.65) | (-1.78)* | (-0.36) | (-1.08) |
| *REGagapop* | 9.503 | 177.27 | 705.88 | 299.210 | 418.46 | 2268.23 |
| | (0.02) | (0.41) | (0.54) | (0.90) | (1.13) | (1.73)* |
| *REGedu* | 6728.855 | -702.46 | -15908.17 | -5086.32 | -5134.78 | -16115.01 |
| | (1.76)* | (-0.22) | (-1.54) | (-2.60)** | (-2.40)** | (-1.95)* |
| $R^2$ | 0.600 | 0.393 | 0.421 | 0.735 | 0.500 | 0.494 |
| *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.

Table A5: Sensitivity Analysis (*HCI* is defined as an industry's wage relative to the average manufacturing sector's wage)

| | FIXED EFFECTS | | | RANDOM EFFECTS | | |
|---|---|---|---|---|---|---|
| | (19)<br>SO2emi | (20)<br>Sootemi | (21)<br>Dustemi | (22)<br>SO2emi | (23)<br>Sootemi | (24)<br>Dustemi |
| *Energy* | 93.138 | 89.914 | 535.753 | 97.683 | 75.662 | 362.826 |
| | (2.52)** | (3.11)*** | (2.60)** | (3.22)*** | (4.08)*** | (2.42)** |
| *PCI* | 0.00867 | 0.0101 | 0.0565 | 0.00754 | 0.0120 | 0.0476 |
| | (0.85) | (0.71) | (1.20) | (0.99) | (1.07) | (1.66)* |
| *HCImanf* | 1155.95 | 1457.56 | 4238.17 | -276.37 | -920.42 | -5551.99 |
| | (0.94) | (1.02) | (1.00) | (-0.32) | (-0.91) | (-1.65) |
| *SIZE* | 4236.04 | 3618.4 | 13335.62 | 102.15 | 1371.41 | 3241.98 |
| | (1.85)* | (1.43) | (1.20) | (0.05) | (0.62) | (0.66) |
| *TFPfe* | -2173.28 | -1507.67 | -1936.12 | -813.63 | -878.39 | -2491.05 |
| | (-1.92)* | (-1.42) | (-0.60) | (-1.76)* | (-1.48) | (-1.72)* |
| *CAP* | -1177.06 | 265.74 | -3117.42 | -2177.33 | -315.50 | -7030.94 |
| | (-0.95) | (0.19) | (-0.78) | (-0.97) | (-0.24) | (-1.22) |
| *RD* | -374.52 | -1119.21 | -4853.82 | -2884.25 | -3401.08 | -17193.73 |
| | (-0.28) | (-0.58) | (-0.81) | (-2.40)** | (-1.98)** | (-2.09)** |
| *REGpros* | -258.22 | -52.34 | -430.05 | -178.19 | -277.24 | -1633.12 |
| | (-0.80) | (-0.12) | (-0.41) | (-0.58) | (-0.67) | (-1.75)* |
| *REGunem* | 198.84 | -225.08 | 486.74 | 1134.26 | 490.03 | 2251.44 |
| | (0.31) | (-0.33) | (0.30) | (1.47) | (0.90) | (1.53) |
| *REGpd* | 5.480 | 3.201 | 2.742 | -0.479 | -0.385 | -2.839 |
| | (2.07)** | (1.08) | (0.28) | (-0.74) | (-0.49) | (-1.18) |
| *REGagapop* | -49.71 | 303.08 | 1253.31 | 88.48 | 316.36 | 1735.49 |
| | (-0.13) | (0.70) | (0.94) | (0.24) | (0.81) | (1.37) |
| *REGedu* | 5934.97 | -1897.27 | -19984.18 | -1729.28 | -3726.84 | -9334.15 |
| | (1.65) | (-0.58) | (-1.72)* | (-0.86) | (-1.57) | (-1.35) |
| $R^2$ | 0.609 | 0.373 | 0.397 | 0.597 | 0.579 | 0.532 |
| *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.

Table A6: Sensitivity Analysis (*TFP* is defined as gross output per worker)

| | FIXED EFFECTS | | | RANDOM EFFECTS | | |
|---|---|---|---|---|---|---|
| | (25) SO2emi | (26) Sootemi | (27) Dustemi | (28) SO2emi | (29) Sootemi | (30) Dustemi |
| *Energy* | 116.849 | 109.13 | 581.599 | 105.098 | 81.559 | 375.311 |
| | (2.96)*** | (3.90)*** | (2.80)*** | (3.37)*** | (5.13)*** | (2.22)** |
| *PCI* | 0.0143 | 0.0101 | 0.0711 | 0.00076 | 0.00293 | 0.0445 |
| | (0.97) | (0.55) | (1.30) | (0.06) | (0.18) | (1.33) |
| *HCI* | -0.0192 | 0.344 | 1.546 | 0.0347 | 0.0951 | 1.016 |
| | (-0.12) | (1.65) | (2.07)** | (0.34) | (0.54) | (1.91)* |
| *SIZE* | 5640.15 | 2497.78 | 9270.73 | -798.68 | -1447.77 | -7706.11 |
| | (1.72)* | (0.78) | (0.81) | (-0.40) | (-0.55) | (-0.93) |
| *TFPoutput* | -46.38 | -39.27 | -154.17 | -6.109 | -13.359 | -90.15 |
| | (-1.39) | (-0.98) | (-1.36) | (-0.21) | (-0.36) | (-0.89) |
| *CAP* | -1759.30 | -305.16 | -4636.10 | -2522.42 | -948.97 | -7755.31 |
| | (-1.24) | (-0.22) | (-1.06) | (-1.06) | (-0.71) | (-1.15) |
| *RD* | -1211.16 | -2366.86 | -9305.54 | -2978.94 | -3973.43 | -16844.54 |
| | (-0.89) | (-1.21) | (-1.41) | (-2.04)** | (-2.19)** | (-2.09)** |
| *REGpros* | -71.49 | 45.62 | -616.67 | 65.274 | 175.23 | -108.76 |
| | (-0.20) | (0.12) | (-0.62) | (0.21) | (0.46) | (-0.11) |
| *REGunem* | 232.13 | -77.44 | 1399.51 | 981.13 | 296.13 | 191.26 |
| | (0.32) | (-0.11) | (0.81) | (1.17) | (0.51) | (0.16) |
| *REGpd* | 5.106 | 1.533 | -3.512 | -0.488 | -0.325 | 0.568 |
| | (2.21)** | (0.51) | (-0.45) | (-0.73) | (-0.48) | (0.21) |
| *REGagapop* | -18.93 | 162.31 | 544.49 | 157.46 | 473.31 | 1842.66 |
| | (-0.05) | (0.37) | (0.44) | (0.43) | (1.21) | (1.29) |
| *REGedu* | 5972.17 | -1294.05 | -15862.34 | -1645.13 | -4379.88 | 1842.66 |
| | (1.57) | (-0.40) | (-1.57) | (-0.68) | (-2.10)** | (1.29) |
| $R^2$ | 0.587 | 0.382 | 0.427 | 0.561 | 0.471 | 0.300 |
| *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.