DISSERTATION

INDUSTRIAL POLLUTION CONTROL IN CHINA: HUMAN CAPITAL, ENVIRONMENTAL REGULATION STRINGENCY AND THE DEVELOPMENT OF ECO-FIRMS

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INDUSTRIAL POLLUTION CONTROL IN CHINA:

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DEDICATION

to my dad

for his love and sacrifice.

ABSTRACT

This thesis analyzes the issue of industrial pollution control in China based on the demand side and the supply side of abatement market. It not only clarifies the incentives behind industrial polluters' abatement decision but also addresses the factors that influence eco-firms' abatement output.

With respect to the demand side of abatement market, the first study subjects the environmental compliance-human capital relationship to a detailed empirical examination. By using a unique cross-sectional dataset of Chinese industrial firms, it investigates the external and internal effects of human capital on firms' environmental performance. The result shows that firms have better environmental compliance because they are 'pushed' into compliance by the internal driver of human capital and 'pulled' to be environmental friendly by the external force of social human capital stock. This finding is robust when we take into account the possible endogeneity of human capital. In addition, evidence from this study suggests that the current situation of weak implementation of environmental supervision and evasion of environmental monitoring could be improved by promotion of internal and external human capital.

With respect to the supply side of abatement market, the second study examines the effect of environmental regulation stringency on industrial abatement demand and individual abatement supply and addresses an eco-firm's output decision in respond to a stricter environmental policy. It quantifies the overall effect of environmental regulation stringency on individual abatement supply by clarifying the directions of regulation induced demand effect and regulation induced market power effect on individual abatement supply of eco-firms based on a simultaneous model. This will be undertaken using a sample of 679 eco-firms in 78 cities covering the period 2003-2007 for environmental regulation stringency of two industrial pollutants, sulfur dioxide (SO_2) and wastewater. From the full sample analysis, the results show that a stricter environmental policy will increase an eco-firm's output. This is confirmed by the insignificant regulation induced market power effect and the significant greater demand effect. However, when estimating the impact of regulation stringency on individual output of firms in different eco-industrial sectors, a distinction is drawn between eco-firms in the sewage treatment sector and those in other eco-industrial sectors; we find that a stricter environmental policy tends to reduce an eco-firm's output in sewage treatment sector.

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LIST OF ABBREVIATION

ADB: Asian Development Bank

CAEP: Chinese Academy for Environmental Planning

CIED: Chinese Industrial Enterprises Database

CMP: Conditional Mixed Process

CRAES: Chinese Research Academy of Environmental Sciences

EMP: Environmental Management Plan

FDI: Foreign Direct Investment

NBS: National Bureau of Statistics

NDRC: National Development and Reform Commission

NERI: National Economic Research Institute

ROA: Return on Asset

SEPA: State Environmental Protection Administration

SOE: State-owned Enterprises

CHAPTER 1 INTRODUCTION

1.1 Background and importance of this research

Rapid industrial expansion is placing increased pressure on China's natural environment. With an average economic growth rate consistently above 8% since 2000 (World Bank, 2007), there is an urgent need to find ways to minimize the consequent environmental impact. The impact is already evident. According to Asian Development Bank (ADB, 2001), among 41 cities ranked by particular air pollution, eight of the worst 10 are in China[1]. In terms of global warming, by 2007, China overtook the United States as the world's biggest producer of carbon dioxide, the chief greenhouse gas; and an estimated 300,000 people die prematurely each year as a result of air pollution.

Coping with the deterioration of the environment has become a crucial task for both scientists and economists. Despite economists trying to quantitatively assess the socioeconomic impact of environmental problems, its potential damage appears to be far beyond our expectations. One of the possible solutions for this is to reduce the various kinds of pollution. Then, how to reduce emission level of industrial pollutants? Abatement is likely to play a significant role in reducing industrial pollution. Industrial polluters make abatement decision by considering their internal resources and the external regulatory environment. On the other hand, abatement in the forms of goods, services and technologies are produced and developed in a specific industry, the so called 'Eco-industry'[2,3]. Industrial polluters have come to greatly rely on an increasing number of eco-firms for their delivery of abatement goods, services and technologies. Therefore, if future economic growth is to be 'greener' in nature, it requires not only clarifying the incentives behind industrial polluters' abatement decision but also addressing the factors that influence eco-firms' abatement output.

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[1] Asian Development Bank (ADB). 2001. Development of Industrial Estates in Sri Lanka, TA 3524-SRI.

[2] According to the definition of OECD and the Statistical Office of the European Commission, eco-industry consists of activities which produce goods and services to measure, prevent, limit, minimize or correct environmental damage to water, air and soil, as well as problem related to waste, noise and eco-system. These include cleaner technologies, products and services which reduce environmental risk and minimize pollution and resource use.

[3] "Eco-industry" has been reviewed in different terminological ways worldwide. It is named as 'environmental protection industry' in China, as 'eco-business' in Japan and as 'environmental industry' in U.S. In other OECD countries, EI is cited as 'environment industry' or 'eco-industry' frequently and as 'environmental goods and services industry' seldom.

1.1.1 Industrial polluters' abatement decision and human capital

To improve industrial polluters' environmental performance, one of the widely adopted instruments is direct intervention through strict environmental regulation. However, the enforcement of environmental regulations varies tremendously on the ground (Wang et al. 2003, Wang and Wheeler, 2005). Local governments' focus on economic growth and firms' resistance towards additional compliance have both brought about weak implementation (SEPA, 2006). Even when local governments are determined to tighten the environmental policies, regulations often end up a game of 'cat and mice' in which polluters make every attempt to evade the regulatory agencies. Given this situation, it is important to understand the drivers behind compliance with environmental regulations.

Human capital is an important internal factor that drives firms to voluntarily comply with environmental regulations. In order to adopt new technologies, firms must have a corresponding stock of human capital to acquire the requisite technical and economic information. Information acquisition may be passive, with firms absorbing information via the day-to-day contact with business associates, or it may be active, with firms engaging in training and technical extension program. In either case, acquisition is greatly facilitated and accelerated by the firm's pre-existing stock of human capital, that is, the education and training of the workforce. Empirically, studies of green technologies adoption typically find that firms with more human capital are more likely to adopt new technologies of abatement and have better environmental performance, all other thing being equal.

The external effect of human capital on firms' environmental performance through community pressure has also been mentioned and studied in the literature. It claims that people with higher education are more likely to be more aware of and evaluate environmental issues differently compared to those with less education, with people with higher human capital more sensitive to surrounding environmental quality (Fishel, 1979; Nelson et al., 1996). Also, in the case of China, Dasgupta et al. (2001) show that informed citizens can have an important impact on pollution via inspections by using a panel data of major polluters from Zhenjiang city and they suggest that regulators should embark on education policies to control pollution.

1.1.2 Abatement producers' output and environmental regulation stringency

In the above section, we have shown that the improvement of industrial environmental performance is made by industrial polluters in relation to their internal and external human capital level. In industrial production, polluters have become increasingly rely on pollution control products and environmental services of eco-firms. Profit-oriented industrial production activities are frequently argued to be at the source and origin of increasing environmental deterioration and source depletion. In this respect, the eco-firms can be seen as an exception. Instead of the resource consumption and environmental pollution of the traditional industrial activities, the pollution control products and environmental services of eco-firms do not only bring economic benefit but also contributing to environmental improvement. Unsurprisingly, the development of eco-firms has then become a major topic for sustainable development and environmental policy discussions.

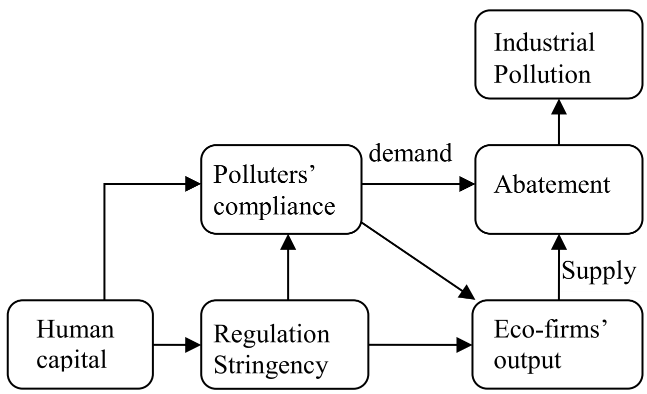
An eco-firm's output decision is determined by both the supply side and demand side of the abatement market. With respect to the demand side, market demand for environmentally sound technologies, products and services is initialized and shaped by government promotion and industrial environmental performance requirements in China (Liu et al. 2006). In this sense, how the government regulates polluting industry, and to what extent it is successful has major consequences for eco-firms' market demand on industrial point sources. The regulation induced demand effect encourages eco-firms to deliver more goods and services. As for the supply side, a stricter environmental policy may reduce the price-elasticity of abatement demand (David, 2006). This acts as a signal which gives an incentive to eco-firms to strategically increase their price through output restriction. The expected higher profits attract new entrants, which my results in a market power effect and decrease each incumbent's output (David et al., 2011). Since environmental regulation is fundamentally related to both the demand for and supply of eco-firm's products and services, it is interesting to analyze the effects of environmental regulation on environmental improvement and pollution control in relation to the development of eco-firms.

1.2 Research Objectives

From the previous section, we learn that abatement is likely to play a significant role for pollution reduction. Our research attempts to address the factors that affect the demand side and supply side of abatement. Figure 1.1 shows the linkage between industrial pollution control and the demand- and supply- side of abatement.

From the perspective of abatement demanders, Chinese industrial polluters' abatement effort can be strengthened by internal and external human capital. In Chapter 3, we aim to clarify the factors behind compliance by using a unique environmental performance data of 2544 industrial Chinese firms. Our particular focus is on the relationship between human capital and compliance which we consider a neglected aspect of the existing research. Conceptually, the relationship between human capital and industrial pollution can be through either an internal or an external route. Within the firm, the implementation of abatement technology is determined by the absorptive capacity of internal human capital endowment: the higher the level of human capital, the better the application within the firm. Outside the firm, higher educated people are more likely to tighten the stringency of environmental regulations by imposing pressure on environmental regulators. We propose that (i) the internal effect of human capital pushes firms to voluntarily comply with environmental regulations and (ii) by enhancing regulatory pressure, the external effect of human capital also pulls firms to have better environmental performance. In addition, we will check robustness of results by accounting for the endogeneity of firms' environmental performance on the corresponding human capital level.

Figure 1. 1 The linkage between industrial pollution control and the supply side and demand side of abatement



From the perspective of abatement suppliers, eco-firms' output supply is closely related to the stringency of environmental regulation. However, in most previous studies, the regulated eco-firm acts as a policy instrument for pollution controlling by government. None of them explicitly address the consequence for the eco-firm itself of the stricter environmental regulation. One of objectives of this study is to examine the regulation stringency on industrial abatement, its consequent indirect influence on an eco-firm's output decision (regulation induced demand effect), and the direct relationship between regulation stringency and an eco-firm's abatement supply in China (which is defined as regulation induced market power effect).

1.3 Contribution

This section highlights the contribution this thesis makes to the existing literature. The first study examines the internal and external human capital effects on industrial firms' compliance decision. We make three contributions to the existing literature. First, the paper sheds light on the internal and external effects of human capital on firms' environmental performance. Our results show that firms have better environmental performance because they are 'pushed' into making compliance decision by internal endowment of human capital, and 'pulled' by external forces of social human capital stock. Accordingly, better environmental performances are achieved based on the internal and external drivers of human capital. Second, we take into account the possible endogeneity of both external and internal human capital. From the internal side, as shown by Grolleaua et al. (2012), environmental-related standards (i.e. ISO 14001 standard) tend to improve the recruitment of professional employees. Such enhancement implies that better environmental performance can deliver more than environmental benefits and firms can strategically use environmental quality standards to attract high educated or high skilled employees who are more sensitive to environmental protection. From the external side, higher educated people may move to cleaner cities since they are more sensitive to environmental quality (in the sense of having higher willingness to pay for quality improvements). In short there is a potential for two-way causality between human capital and environmental performance. Most studies reviewed in section 2 do not concern themselves with the endogeneity of human capital; our study on the other hand, better identifies the causal relationship between environmental performance and human capital. Our third contribution is that, we build a new database of firm-level data on environmental performance for China. Blackman and Kildegaard (2010) argue that most studies in developing countries rely on self-reported firm-level environmental data, which can be unreliable. However, instead of self-reported information, the environmental performance data we use is evaluated and compiled by a government environmental administration. The environmental performance might be different from regulator-reported than self-reported. Thus, our study may fill gap in the literature by providing evidence from the regulator-reported environmental data of Chinese industrial polluters[4].

The second study addresses the overall effect of regulation stringency on individual abatement output. In most of the environmental economics literature, as David and Sinclair-Desgagné (2010) indicated that pollution abatement is generally assumed to be set only by industrial polluters, based in turn on relevant regulatory, technological or output market considerations, but omitting the

[4] A paper based on this chapter is forthcoming.

bilateral relationship with actual suppliers, eco-firms. In this study, we clarify the directions of regulation induced demand effect and regulation induced market power effect on individual abatement supply of eco-firms. To the best of our knowledge, our empirical study is the first to shift focus from industrial polluters to abatement suppliers. We attempt to fill this gap in this line of research by providing data from Chinese eco-firms. In addition, we test the existence of business stealing effect in Chinese eco-firms and quantify the regulation induced demand effect on individual abatement output. A distinction is drawn between eco-firms in the sewage treatment sector and those in other eco-industrial sectors; we find that a stricter environmental policy tends to reduce an eco-firm's output in sewage treatment sector .

Furthermore, we take into account the fact that regulatory stringency differs with respect to different kinds of target pollutants due to different levels of abatement difficulty as well as the implementation length of emission standards on different pollutants. We select industrial SO_2 emissions and industrial wastewater emission as two target pollutants and use levy charges of industrial SO_2 and treatment prices of industrial wastewater to measure their corresponding regulatory stringency respectively. Hence, the proxies are able to compare the stringency of environmental regulation across cities, even if they differ with respect to different target pollutants. The proxies for policy stringency with respect to different pollutants help us obtain insights and provide implications in terms of different targeted pollutants.

In sum, the hope is that this thesis provides a useful contribution to the field of industrial pollution control in the developing countries. Findings are clear and well-defined and open up a number of potential avenues for future research.

The organization of this thesis is the following. In the second chapter, we give a simple introduction on the current situation of industrial pollution control, industrial environmental performance and its corresponding human capital level across regions and the development of eco-firms in China. Chapter 3 investigates the external and internal effects of human capital on firms' environmental performance. Chapter 4 examines eco-firms' response to a stricter environmental policy and quantifies the regulation effect on industrial abatement demand and individual abatement output of eco-firms. Finally, we conclude in Chapter 5.

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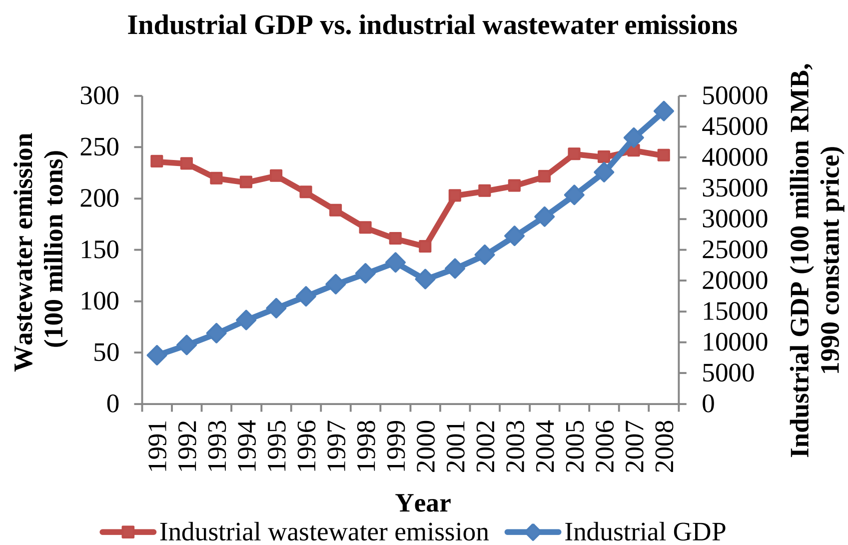
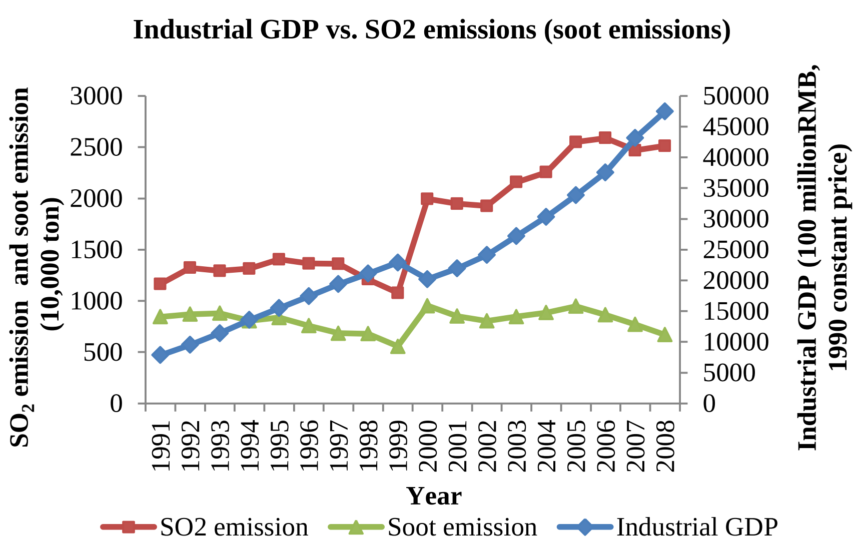
CHAPTER 2 CHINA'S INDUSTRIALIZATION, INDUSTRIAL ENVIRONMENTAL PERFORMANCE AND THE DEVELOPMENT OF ECO-FIRMS

2.1 Industrialization and emission

The rapid industrialization is considered as one of significant components of China's economic success. In the past decade, the industrial GDP has experienced an unprecedented rapid expansion. The value of industrial GDP at the end of 2008 is 7 times that at the beginning of 1991(with 1990 constant price).

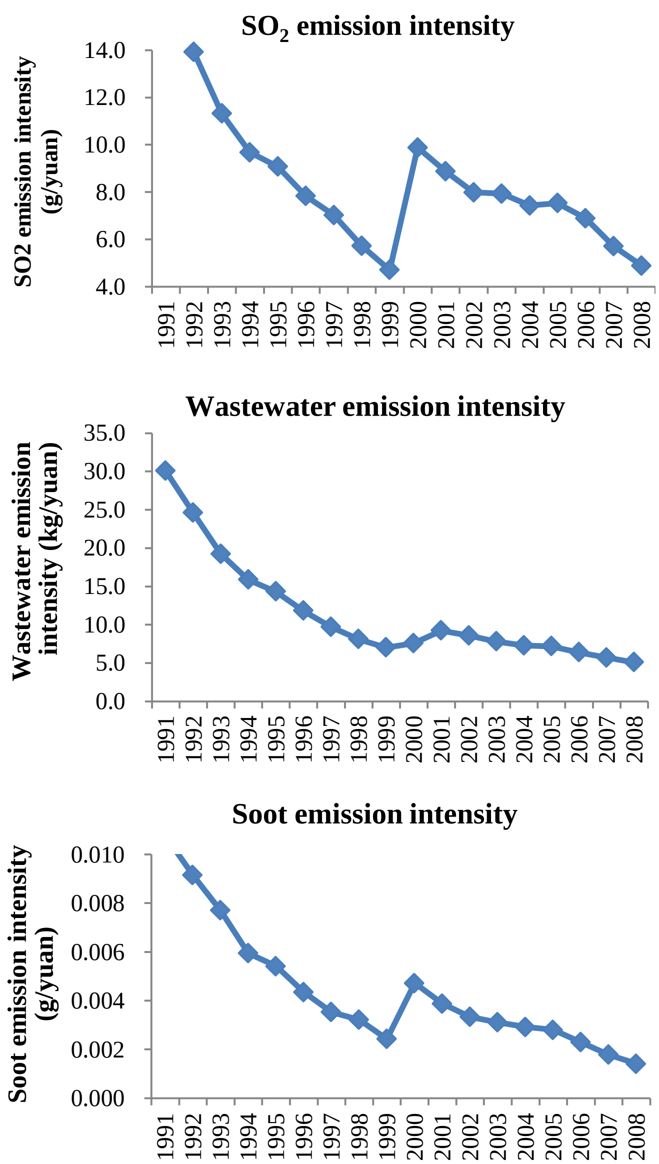
Figure 2. 1 Evolution of real industrial GDP and industrial emissions





Despite the dramatically expansion of industrialization over the period 1991-2008, Figure 2.1 illustrates that industrial emissions of wastewater, SO_2 and soot, actually decreased for at least part of this period. However, industrial SO_2 emissions appear to have increased since around the year 2005. Nevertheless, in the face of such rapid industrial expansion the absence of rapidly increasing pollution levels suggests that Chinese environmental policies have proved reasonably effective. Figure 2.2 provides further evidence to support this assertion by illustrating the emissions of three pollutants (industrial wastewater emission, industrial SO_2 emission and industrial soot emission) in the forms of intensities. All three intensities can be found to fall over time.

Figure 2. 2 Emission intensity of Industrial wastewater, SO_2 and soot (1991-2008)

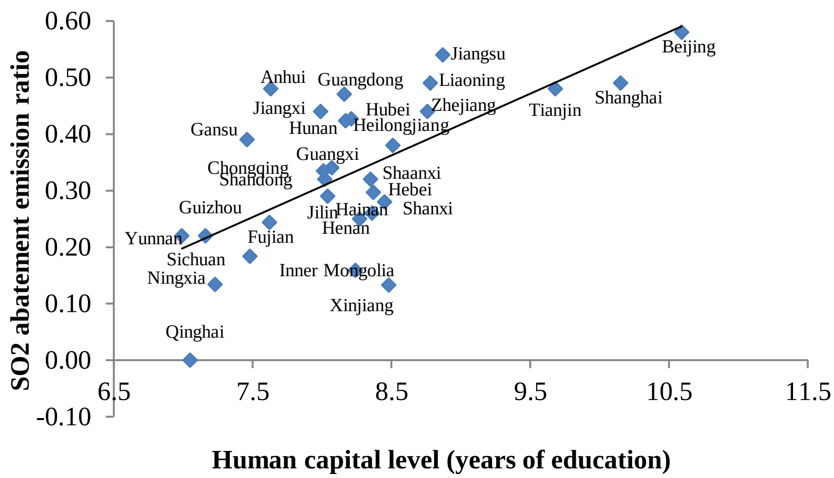


This record is considerable, but how to keep the continued rapid decline in pollution intensity or just to stay even with the pace of industrial growth are still the major challenges for central and local government.

2.2 Human capital and industrial environmental performance across regions in China

According to CRAES (1994), although pollution abatement in the past decades has been sufficient to maintain at least constant levels of industrial wastewater emissions and flue soot and dust emissions from coal combustion at nation level, the regulatory coverage is by no means universal. Even in some areas where there exists well-conceived environmental laws and policies, the enforcement of environmental policy varies tremendously on the ground. As expected in Chapter 3, a place with higher human capital level is associated with more stringent regulation, resulting in better industrial environmental performance. We draw the scatterplots to show the possible relationship between human capital and industrial environmental performance for each province in China with respect to industrial wastewater, industrial SO_2 and industrial soot [5].

Figure 2. 3 Industrial SO_2 abatement emission ratio vs. human capital level (2004)



For all three pollutants as shown in Figure 2.3, Figure 2.4 and Figure 2.5, most points cluster in a band running from lower left to upper right, implying a positive relationship between

[5] Sulphur dioxide emissions refer to the volume of sulphur dioxide emitted by industrial production process. Soot emissions emanate specifically from the process of fuel burning by industrial activity. The diameter of soot particles is less than 0.1μm (often referred to as PM10) and these finer particles are damaging to health, particularly in the form of respiratory problems.

abatement-emission ratio [6] and regional human capital level. We have an intuitive grasp of the positive relationship between industrial environmental performance and human capital from the three scatterplots diagrams. In Chapter 3, we attempt to provide additional evidence by an empirical study focusing on analyzing human capital's effect on Chinese industrial polluters' compliance decision.

Figure 2. 4 Industrial wastewater abatement-emission ratio vs. human capital level (2004)

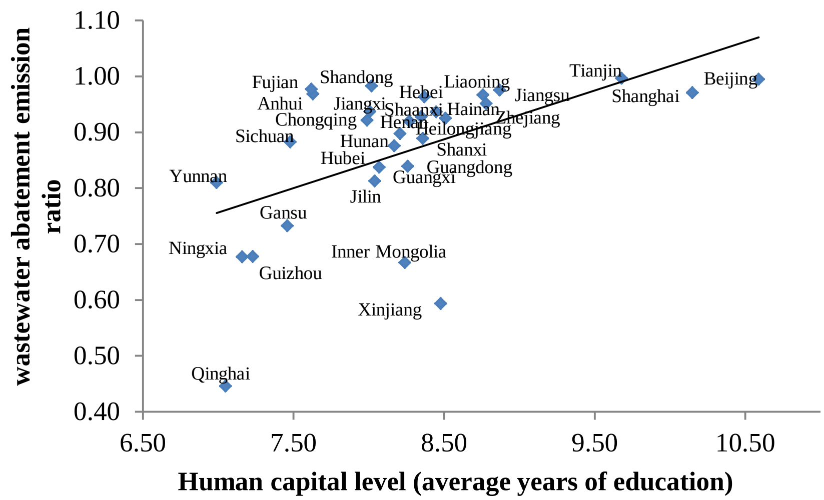
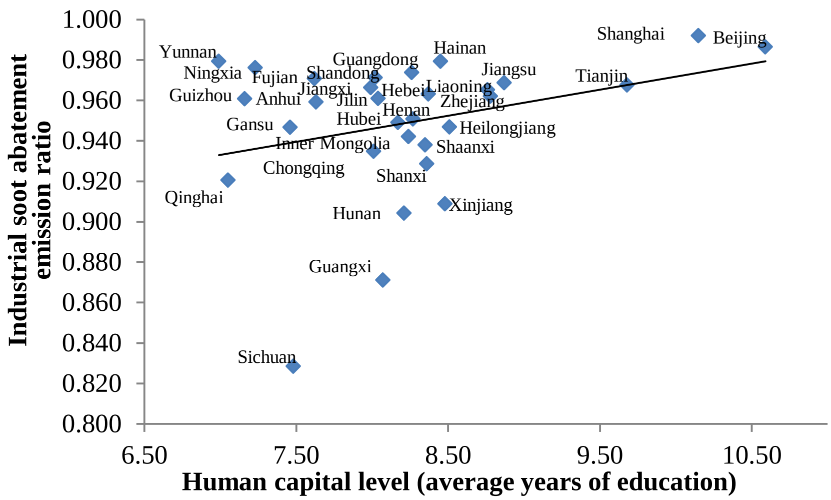


Figure 2. 5 Industrial soot abatement-emission ratio vs. human capital level (2004)



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[6] Abatement-emission ratio is defined as average abatement per unit of emission which captures the effort made to reduce the emissions and so can be used to measure industrial environmental performance.

2.3 The development of eco-industry

Since 2000, an environmental campaign aimed at establishing a circular economy has been promoted by Chinese government. It has triggered a huge domestic market for abatement products and services. For instance, according to Chu et al. (2002), the annual construction cost of wastewater treatment infrastructures was predicted to increase to 6.48-8.02 billion Yuan in 2020 and gradually decrease to 2.56-3.97 billion Yuan till 2050. Besides, an additional amount of 48.6-50.2 billion Yuan and 55.9-76.1 billion Yuan will be required annually in terms of operation cost in 2020 and 2050. However, in contrast to this huge market demand for abatement, the eco-industry in China has not been stimulated effectively by government regulation and public pressure, which had only 102.2 billion Yuan in sales in 2002[7]. This just accounts for less than 1% of China's GDP. Hence, compared to rapid economic growth, Chinese eco-industry is relatively underdeveloped.

Figure 2. 6 Eco-industry's turnover in sales and proportion to GDP in relevant years

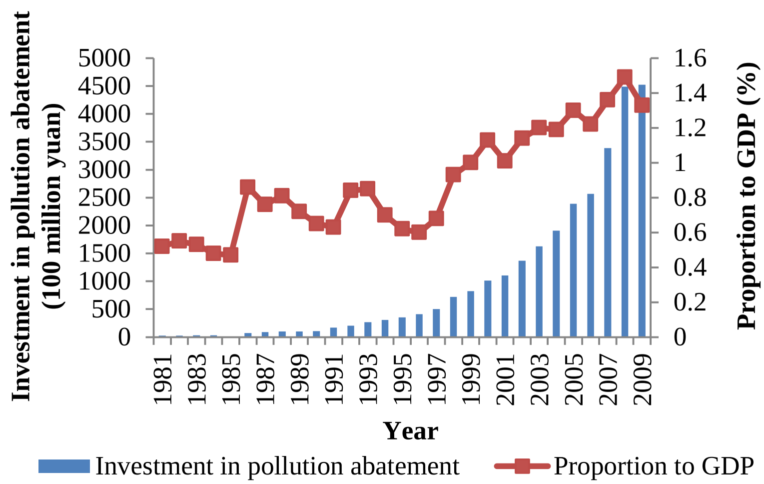
Figure 2.6 illustrates the evolution of the eco-industry's turnover in sales and its proportion to GDP in the period 1993-2008. As shown in Figure 2.3.1, the absolute amount of turnover in sales might look considerable; the development of eco-industry appears a gradually increasing trend indicated by the proportion of sales to GDP which increased from 0.80% in 1993 to 1.49% in 2008.

Figure 2.7 shows the evolution of investment in pollution abatement and its proportion to GDP during the period 1981-2009. As shown in Figure 2.3.2, despite the gradually increase of social abatement investment, the abatement investment per unit GDP has fluctuated and stagnated

[7] The annual sales and GDP are calculated based on 1990 constant price.

at least until 1997. And even the highest level of 1.49% in 2008 is still lower than what can be witnessed in many developed countries. According to World Bank (1997), when the social abatement investment accounts for 1.0-1.5% of GDP, the increasingly growing tendency of the environmental pollution can be just alleviated; only if this proportion reaches to 2.0-3.0%, the environmental quality can be improved [8]. So, the eco-industry in China is still at the preliminary stage.

Figure 2. 7 Annual investment in pollution abatement and proportion to GDP



The underdevelopment of eco-industry has negative economic consequences. Eco-industry's underdevelopment is likely to result in large enforcement cost of environmental policy and impose a heavy financial burden on central and local government. Besides, it is argued that the annual national wealth loss in China caused by environmental pollution and ecological deterioration represents 3.5-7.7 percent of GDP (Liu, et al., 2006). Hence, what is behind China's limited capacity to develop eco-industry? Given the increasingly serious environmental problems, we try to answer this question in Chapter 4.

[8] World Bank (1997), World Development Report, 1997: Environment and Development, Washington, D.C., World Bank.

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CHAPTER 3 ENVIRONMENTAL COMPLIANCE AND HUMAN CAPITAL: EVIDENCE FROM CHINESE INDUSTRIAL FIRMS

3.1 Introduction

The increasingly serious level of industrial pollution poses a challenge to China's fast economic growth. Despite well-conceived laws, enforcement varies tremendously on the ground (Wang et al. 2003, Wang and Wheeler, 2005). Local governments' focus on economic growth and firms' resistance towards additional compliance have both brought about weak implementation (SEPA, 2006). Given this situation, it is important to understand the drivers behind compliance with environmental regulations and so, in this paper, analyze the factors behind compliance by using a unique environmental performance data of 2544 industrial Chinese firms. Now, there is already a large literature on regulatory compliance. Our particular focus is on the relationship between human capital and compliance which we consider a neglected aspect of the existing research. Conceptually, the relationship between human capital and industrial pollution can be through either an internal or an external route. Within the firm, the implementation of abatement technology is determined by the absorptive capacity of internal human capital endowment: the higher the level of human capital, the better the application within the firm. Outside the firm, higher educated people are more likely to tighten the stringency of environmental regulations by imposing pressure on environmental regulators. Based on the above descriptions, we hypothesize that (i) the internal effect of human capital pushes firms to voluntarily comply with environmental regulations and (ii) by enhancing regulatory pressure, the external effect of human capital also pulls firms to have better environmental performance.

We make three contributions to the existing literature. First, the paper sheds light on the internal and external effects of human capital on firms' environmental performance. Our results show that firms have better environmental performance because they are 'pushed' into making compliance decision by internal endowment of human capital, and 'pulled' by external forces of social human capital stock. Accordingly, better environmental performances are achieved based on the internal and external drivers of human capital.

Second, we take into account the possible endogeneity of both external and internal human capital. From the internal side, as shown by Grolleaua et al. (2012), environmental-related standard (i.e. ISO 14001 standard) tend to improve the recruitment of professional employees. Such enhancement implies that better environmental performance can deliver more than environmental benefits and firms can strategically use environmental quality standards to attract high educated or high skilled employees who are more sensitive to environmental protection. From the external side, higher educated people may move to cleaner cities since they are more sensitive to environmental quality (in the sense of having higher willingness to pay for quality improvements). In short there is a potential for two-way causality between human capital and environmental performance. Most studies reviewed in section 2 do not concern themselves with the endogeneity of human capital; our study on the other hand, better identifies the causal relationship between environmental performance and human capital.

Our third contribution is that, we build a new database of firm-level data on environmental performance for China. Blackman and Kildegaard (2010) argue that most studies in developing countries rely on self-reported firm-level environmental data, which can be unreliable. However, instead of self-reported information, the environmental performance data we use is evaluated and compiled by a government environmental administration. The environmental performance might be different from regulator-reported than self-reported. Thus, our study may fill gap in the literature by providing evidence from the regulator-reported environmental data of Chinese industrial polluters.

The remainder of the paper is organized as follows. In section 2, we give a brief review of related literature on environmental performance and human capital, highlighting their connection though internal and external paths. Section 3 presents the data and explains the empirical methodology. Section 4 estimates the econometric models and discusses the results obtained. The final section concludes and derives policy implications.

3.2 Related literature

Human capital is an important internal factor that drives firms to voluntarily comply with environmental regulations. In order to adopt new technologies, firms must have a corresponding stock of human capital to acquire the requisite technical and economic information. Information acquisition may be passive, with firms absorbing information via day-to-day contact with business associates, or it may be active, with firms engaging in training and technical extension program. In either case, acquisition is greatly facilitated and accelerated by the firm's pre-existing stock of human capital, that is, the education and training of the workforce. Empirically, studies of green technologies adoption typically find that firms with more human capital are more likely to adopt new technologies of abatement and have better environmental performance, all other thing being equal. For instance, in their study of Indonesian water polluters, Pargal and Wheeler (1996) find that average education level of employment is correlated with lower emission of water pollutant.

Dasgupta et al. (2000) analyze the extent of adoption of ISO 14001 type environmental management practice by firms in Mexico. They show that firms with highly educated workers have significantly greater environmental management effort and compliance. Gangadharan (2006) also yields a further confirmation of the positive role of internal human capital on firms' environmental performance using survey evidence from manufacturing industries in Mexico. Manderson and Kneller (2012) suggest that firms with a greater intensity of human capital may have greater opportunities for technological advancement of pollution abatement though they fail to find significant result. Finally, Blackman and Kildegaard (2010) use original firm-level survey data to identify the factors that drive Mexican firms' adoption of clean technologies and find that the key driver of adoption is the firms' human capital.

The external effect of human capital on firms' environmental performance through community pressure has also been mentioned and studied in the literature. Fishel (1979) and Nelson et al (1966) claim that people with higher education are more likely to be more aware of and evaluate environmental issues differently compared to those with less education, with people with higher human capital more sensitive to surrounding environmental quality. Goetz et al. (1998) argue that changes in human capital modify individuals' appreciation of environment independently of income, thereby causing changes in behavior that are measurable at the state level in the United States. They also show that educated decision-makers are more likely engage in community activities that improve the environment and persuade manufacturers to make effort in pollution abatement since those people are more likely to be aware of detrimental effects of environmental pollution on their health. Goldar and Banerjee (2004) find that the percentage change in the local literacy rate help explain water quality in river sections downstream from Indian industrial clusters. In the case of China, Dasgupta and Wheeler (1997) analyze the determinants of citizens' complaints in 29 Chinese provinces and find that they are an increasing function of the levels of education. Dasgupta et al. (2001) show that informed citizens can have an important impact on pollution via inspections by using a panel data of major polluters from Zhenjiang city and they suggest that regulators should embark on education policies to control pollution. Cole et al. (2008b) examine the possible factors that may influence industrial pollution emissions in China by using a panel of 15 industries and their results suggest that regions with greater levels of education may have more stringent regulations.

In addition to the possible better environmental performance resulting from efficient absorption and effective adoption of clean technology by human capital, several other studies have examined whether and how environment-related standards improve human resource management.

Firms may adopt voluntary environmental initiatives to improve human resource management by facilitating recruitment, increasing employees' morale and motivation, and thereby raising workforce productivity (Halkos and Evangelinos, 2002). Mzoughi et al. (2007) show that ISO 14001 registration amongst French agrofood firms was mainly driven by the desire to improve human resource management. More recently, Grolleaua et al. (2012) investigate the impact of environmental-related standards on employees' recruitment using a bivariate probit model and find that firms can strengthen their 'greenness' by attracting environmentally sensitive talent employees. In summary therefore, it is necessary for us to take into account the endogeneity of firms' environmental performance on the corresponding human capital level.

3.3 Empirical methodology and data

3.3.1 Environmental performance data

The firm level data employed in this paper are compiled from State Bureau of Environmental Protection and China's industrial enterprises database (survey data 2004); the city-level data are compiled from China Environmental Statistics Yearbook (2005), and sector level data are sourced from China Industrial statistics yearbook (2005). The original environmental performance rating data set is drawn from the environmental information disclosure system data (2004) of State Bureau of Environmental Protection with a total 3729 firms from SIC 4-digit industrial sectors covered 29 cities, 9 provinces (including autonomous regions and municipalities) in 2004.

Table 3. 1 Grading System of Firm Environmental Performance

Color	Performance	Criteria
Green	Excellent	In addition to meeting the requirement for Blue, the enterprise also obtains ISO 14000 certificate or passes cleaner production audit. Corporate environmental management reaches an advanced level.
Blue	Good	The emission level is lower than the relevant national emission standard. The enterprise has high level corporate environmental management.
Yellow	Fair	The emissions on the whole comply with relevant national emission standard. Emission level exceeding relevant national emission standard or non-compliance occurs occasionally.
Red	Poor	Emissions cannot comply with relevant national emission standard or more serious pollution accident happens.
Black	Very Poor	The emission level greatly exceeds relevant national emission standard and causes serious environmental impact or the most serious kind of pollution accident happens.

The rating of firms' environmental behavior is based on the public color-coded ratings system and was proposed by the State Environmental Protection Administration (SEPA) in 2003 in cooperating with the World Bank. In the data set for 2004, the batch of 29 pilot cities includes Nanjing, Wuxi, Suzhou, Changzhou, Nantong, Zhenjiang, Xuzhou, Yancheng, Taizhou and Yangzhou in Jiangsu provinces; Hangzhou, Ningbo and Wenzhou in Zhejiang province; Jinan, Yantai and Zibo in Shandong province; Huainan, Huaibei, Tongling Maanshan and Chaohu in Anhui province; Huhehot in Inner Mongolia autonomous region; Jiayuguan in Gansu province; Zhuzhou and Changde in Hunan province; Jiazuo in Henan province, Liuzhou in Guangxi Zhuang autonomous region and Chongqing municipality. According to the documentation provided in SEPA (2004), the grading system draws on 15 indicators (see Table A3.1 in Appendix) and the conceptual scheme of the grading system is shown in Figure A3.1 in Appendix. On the basis of the grading system, firms' environmental performance is divided into five symmetric rating categories, ranging from black (the worst performance) through red, yellow and blue, to green (the best performance). Table 3.1 summarizes the ranking system criteria for each category. Considering the different levels of economic development and the heterogeneity in the stringency of environmental regulation across regions, it is quite possible that some local governments have loose evaluation standards. Therefore, we cannot rule out the possibility that in some regions green/blue status are achieved by weak standards rather than by firms' strong performances.

Table 3.2 presents the distribution of firms that participate in environmental ranking system by cities in 2004. In the whole sample, 56.2% of the sample firms are grouped in Hangzhou, Nanjing, Ningbo and Suzhou, these 4 eastern coastal cities, reflecting the size and situation of regional industrial agglomeration in China.

To maintain some confidentiality, the environmental information disclosure system of State Bureau of Environmental Protection only provides information on firms' names, locations and levels of environmental performance. Hence, in order to obtain more firm-level and city-level characteristics, we use each firm's name and its location to match the environmental performance dataset to the China Industrial Enterprises Database (2004) and the dataset of China Industrial Yearbook (2005). The China Industrial Enterprises Database collects almost all important aspects of a firms' operation covering firms from all business sectors. We use a subset of the database data that contains the industrial firms in our environmental performance data and their detailed firm-level information, including ownership types, industry code, city code, R&D expenditure, sales, employee education level, asset, number of employment, value of exports, profits and industrial value added and etc. The China Environmental Statistics Yearbook contains information about the air quality of city and the amount of pollution emission of each industry. After matching the data sets, we obtain a sample of 2554 firms from 29 cities. For each business we have information on firm characteristics such as levels of environmental performance, ownership types, firm size, firm age, industrial code, annual R&D expenditure, annual profit, annual value of exports, annual sales, total asset value and etc, and city-level variables such as GDP per capita, unemployment rate, population density and market-oriented degree. The definitions and statistical descriptions of all variables used in our analysis are presented in the Appendix Table A3.3 and Table A3.4 respectively.

Table 3. 2 City profiles: all sample (2004)

City	Rating of Environmental performance						Population	GDP/capita	Air quality index
	Green	Blue	Yellow	Red	Black	No. of firms	(10000 persons)	(10000 yuan)	
Changde	2	7	11	2	1	23	601.05	1.83	0.87
Changzhou	7	23	12	2	0	44	348.97	3.63	0.82
Chaohu	4	12	14	11	0	41	453.96	0.89	0.85
Chongqing	0	13	6	4	2	25	1017.57	1.33	0.66
Hangzhou	48	100	192	55	5	400	651.68	4.91	0.80
Huaibei	6	31	16	3	3	59	209.39	1.50	0.82
Huainan	2	18	33	5	2	60	233.58	0.98	0.85
Huhehot	13	41	25	7	1	87	214.70	3.16	0.85
Jiaozuo	0	20	5	2	0	27	345.50	1.48	0.64
Jiayuguan	1	6	7	3	0	17	16.76	2.52	0.90
Jinan	10	17	19	4	2	52	590.08	3.67	0.57
Liuzhou	13	39	35	7	1	95	210.24	1.92	0.75
Maanshan	2	18	8	3	1	32	124.39	2.95	0.95
Nanjing	74	269	208	38	5	594	583.60	3.55	0.81
Nantong	18	35	47	12	4	116	773.79	3.51	0.88
Ningbo	84	261	116	4	1	466	552.69	6.04	0.92
Suzhou	140	278	198	19	3	638	598.85	6.03	0.84
Taizhou	10	46	40	10	4	110	502.77	3.17	0.79
Tongling	10	57	53	13	3	136	71.63	2.98	0.86
Wenzhou	8	31	15	0	1	55	746.19	4.58	0.97
Wuxi	21	77	71	12	3	184	447.19	5.90	0.79
Xuzhou	5	23	34	7	4	73	916.85	3.16	0.60
Yancheng	5	30	20	3	0	58	798.28	1.59	0.67
Yangzhou	3	14	31	4	2	54	454.29	3.22	0.82
Yantai	8	16	14	10	6	54	354.51	2.32	0.99
Zhenjiang	24	93	40	5	4	166	267.21	3.50	0.73
Zhuzhou	1	18	11	4	1	35	370.93	2.48	0.53
Zibo	6	5	5	12	0	28	450.51	2.40	0.81
Total	525	1598	1286	261	59	3729			

In some cases, firms cannot be matched. The information on dropped observations is summarized in Table A3.2. As shown above, the environmental information disclosure system database only provides firms' information on levels of environmental performance and their locations; we cannot apply the common data imputation technique to deal with the missing data since we cannot find additional information to impute the missing values of all independent variables of the deleted observations. To check whether there exist sample selection bias or not, we carry out Chi-square significance tests by comparing the matched sample and full sample. Chi-square test of the null hypothesis is that there is no sample selection bias. First, we calculate the Chi-square test statistic only considering the distribution of 5-level environmental performance. After calculation, we get χ^2 = 0.106 (critical value of χ^2=9.488 with 4(=5-1) degree of freedom at the 1% significant level). Since χ^2 statistic is smaller than its critical value, we cannot reject the null hypothesis of no bias. Next, we calculate χ^2 statistic by considering the distributions of environmental compliance in each city. Since χ^2 statistic (0.595) does not exceeded the critical value for 1% significant level (80.15) with 112(=28×4) degree of freedom we accept the null hypothesis that there is no selection bias.

Table 3. 3 Environmental performance and firms' distribution

Environmental compliance	Over-compliance		Compliance	Non-compliance	
Color	Green	Blue	Yellow	Red	Black
No. of firms	362	1072	820	253	47
Percent	14.2	42.0	32.1	9.9	1.8
Cum.	14.2	56.1	88.3	98.2	100.0

Table 3.3 summarizes the distribution of firms. To simplify the subsequent analysis, we define the levels of compliance as over-compliance, compliance and non-compliance according to the criteria of ranking as shown in Table 3.1. Category green and blue are combined to obtain over-compliance and it represents 56.1% of firms in the data. The firms in these two categories have exceeded the environmental requirements and claimed to have established high-level environmental management in their organization. Category yellow is defined as compliance (32.1% of firms) and includes firms that consistently observe the environmental regulations or usually comply with emission standards, though they sometimes fail in specific points. Categories red and black include firms that usually fail to obey environmental regulations and even cause the pollution accidents. Categories red and black are merged to obtain non-compliance since each of them accounts for a small percentage of total firms.

3.3.2 Empirical methodology and variables

To measure the actual outcome from internal and external effects we use data on the grading of firms' environmental performances. Besides a variety of firm- and industry- characteristics, we also include a number of other control variables designed to capture characteristics of the location of firm that could influence the level of regulatory activity it faces.

The dependent variable environmental compliance C_{ji} is a function of firm- and city-PEOPLE characteristics, as well as INDUSTRY and LOCATION variables.

$$C_{ji} = f(FPEOPLE_{ji}, FX_{ji}, CPEOPLE_{j,} CX_{j}, INDUSTRY_{ji}, LOCATION_{j}) \quad (5)$$

Following previous research studies, in addition to human capital, some other determinants that may have effects on environmental performance are also included in the estimation model as explanatory variables. In full, we estimate the following model,

$$\Pr(Compliance = m \mid x_i) = F(\tau_m - X\Phi) - F(\tau_{m-1} - X\Phi) \quad (6)$$

$$\begin{aligned} \text{and } X\Phi + \varepsilon &= \sum \alpha_h FPEOPLE_{jih} + \beta_1 Exports + \beta_2 RD_{ji} + \beta_3 ROA_{ji} + \beta_4 SIZE_{ji} + \sum \rho_n OWNERSHIP_{jin} \\ &+ \sum \gamma_h CPEOPLE_{jh} + \beta_5 AIRquality_j + \sum \varphi_h CPEOPLE_{jh} \times AIRquality_j + \beta_6 UNEMP + \beta_7 POPden_j \\ &+ \beta_8 Market_j + \beta_9 GDPcap_j + \beta_{10} INTso2_s + \beta_{11} INTwater_s + \beta_{12} INTsoot_s + \beta_{13} WEST + \beta_{14} EAST + \varepsilon_{ji} \end{aligned}$$

where F is the cumulative distribution function of the error term ε and F is normal with $VAR(\varepsilon)=1$. τ_m and τ_{m-1} are two cutpoints (thresholds) and two cutpoints leads to the three levels of firms' environmental performance: over-compliance, compliance and non-compliance. FPEOPLE is a vector of share of employment with different education levels for firm: share of employment with college education and above ($FCOLLEGE_{ji}$), share of employment with senior high school education ($FSENIOR_{ji}$) and share of employment with primary school education and below ($FPRIMARY_{ji}$). CPEOPLE is a vector of ratios of population with different education levels in a city including the share of population with college education and above ($CCOLLEGE_j$), share of population with senior high school education ($CSENIOR_j$) and share of population with primary school education and below ($CPRIMARY_j$). In both cases, the reference group in our study is population with junior high school education.

First, let us review the variables of PEOPLE characteristics, those influencing the marginal benefits and marginal cost from pollution abatement at a particular firm. On the marginal cost side, we have the percentage of employees with different education levels within the firm ($FCOLLEGE_{ji}$, $FSENIOR_{ji}$ and $FPRIMARY_{ji}$). On the marginal benefit side, we also have the percentage of the population with different education levels in the city ($CCOLLEGE_j$, $CSENIOR_j$ and $CPRIMARY_j$, σ_{hq} in Eq (2)), representing the sensitivities to environmental quality of different educational groups.

Following the conceptual framework and the previous literature, we would expect to find positive signs for the coefficients in the high human capital levels of both firm and city.

Next we define the firm-level explanatory variables that may affect a firm's environmental performance. Research and development expenditure (RD), a proxy for the innovation within firms, will often lead to the improvements to the firm's production process, might resulting in less need for energy per unit output. Thus, we might expect innovation expenditure to reduce a firm's emission of pollutants. Firm size (SIZE) is measured by the natural logarithm form of employment. Cole et al. (2008a) investigate the role played by foreign direct investment on firms' environmental performance and find that the size of firm is negatively related to its energy intensity and larger sized firms tend to have better environmental performance. We therefore expect a positive relationship between firm's size and its environmental performance. Age (AGE) is defined as the number of years from the year of their registration to year 2004, given the likelihood that newer firms may use more modern, cleaner technology to reduce the emissions (Cole et al., 2008a). A measure of the share of sales of each firm that is exported (Export) given the possibility that exporters may be cleaner in order to serve export market in the developed world where consumers are typical environmentally conscious. A proxy for firm's financial performance is ROA given that firms with better financial performance often have better environmental performance.[9]

We also include the firm-level ownership dummies in our empirical model. The 2004 survey data of China Industrial enterprises database defined six types of firm ownership. In particular, they are state-owned enterprises (SOE), foreign-owned enterprises (FDI), privately-owned enterprises (PRIVATE), public-listed companies (PUBLIC), collectives (COLLECTIVE), and non-state-owned limited companies (LIMITED). These six types of ownership are mutually exclusive. SOEs include domestic SOEs, alliances of SOEs, and unlisted state-owned limited companies. Foreign-owned enterprises include joint ventures with Hong Kong, Macau, Taiwan (HMT) and other foreign investors. They also include HMT wholly-owned companies, HMT shareholding companies, wholly foreign owned companies, and foreign shareholding companies. Privately-owned firms include private limited companies, private shareholding companies, proprietorships and partnerships. Public-listed companies are domestic public-listed companies. Collectives include companies that are registered as domestic collectives or domestic alliances of collectives. To compare the different environmental performances of foreign-owned enterprises, we make a

[9] As shown by Wang and Wheeler (2005), the cost of abatement technology is usually fixed, but pollution and thus government fines increases with output, so the relative cost of environmental compliance decreases with output.

separation of HMT related firms (including HMT wholly-owned firms and HMT shareholding firms) and other foreign related firms (including wholly foreign owned firms and foreign shareholding firms).

The control variables of industrial characteristics include proxies for industrial dirtiness (INTso2, INTwater and INTsoot calculated as industrial emissions scaled by industrial value added) given the possibility that the dirtier the industry a firm included in, the worse environmental performance it shows.

Our explanatory variables of city and regional characteristics include AIRquality Unemployment, POPdensity, Market, EAST and WEST. Using socioeconomic characteristics to identify the effect of community pressure may pick up any number of unobserved determinants of formal and informal regulatory pressures. We use the local environmental conditions, measured by air quality (AIRquality) as a proxy for the social effort made to maintain or improve the environmental quality given the possibility that the more stringent environmental regulations might be imposed to maintain the better environmental condition. The proxies for local protectionism include Unemployment and Market. 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 cities 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 tolerate non-compliance with environmental regulations. The variable Market is obtained from the NERI (National Economic Research Institute) Index of Marketization of China's Provinces 2006 Report to measure the effort of local government to reduce local protectionism. A higher value indicates a lower entry barrier to the local market and thus smaller local protection. We expect a city with a higher Marketization index is associated with better environmental performance of the firms located in that city. Population density (POPdensity) may affect firms' environmental behaviors through two ways. On the one hand, a densely populated area may imply there are more people adversely affected by pollution and hence opposition to such plants may be greater. Conversely, a pollution intensive plant may be less 'visible' in a densely populated, urban area and hence may escape the attentions of the local population (Cole et al., 2005). EAST and WEST are regional dummies to capture the regional heterogeneity while the central part of China works as the reference group.

Finally, we add interactions between the air quality and the share of population in each education group to see whether the coefficient on the interaction terms differ across different educational groups, which also indirectly reflecting the different susceptibilities from different educational group on environmental conditions.

3.3.3 Potential problem and instruments selection

Following the instrumental-variables strategy of Fisman and Svensson (2007), we use industry-location average share of college and above educated employees (ICOLLEGE) as an instrument al variable for FCOLLEGE. Our identifying assumption to deal with this problem is that $FCOLLEGE_{ji}$ can be decomposed into two terms, one industry-specific, and the other particular to the firm: $FCOLLEGE_{jsi} = Fcollege_{jsi} + ICOLLEGE_{js}$. Here, $ICOLLEGE_{js}$ denotes the (average) share of college and above educated employees common to location j and industry s, which in turn is a function of the underlying characteristics inherent to that particular industry location, while $Fcollege_{ji}$ denotes the specific component. We assume that the industry-specific part of human capital is determined by industry-specific components, we assume that $ICOLLEGE_{j}$ is exogenous to the firm, and hence uncorrelated with the error term ε. If this assumption is valid, we may use $ICOLLEGE_{js}$ to instrument for $FCOLLEGE_{jsi}$, since $CORR(ICOLLEGE_{js}, \varepsilon) = 0$. In such a specification, using industry-location averages as an instrument for firm-level $FCOLLEGE_{jsi}$ gets rid of the biases resulting from omitted variables that are correlated with $FCOLLEGE_{jsi}$ at the firm level. In our case, the industry-location averages we use should serve to mitigate the effects of measurement error which is a common concern when using micro-level data, since we generally think of these errors as being largely idiosyncratic to the firm, and hence uncorrelated with the average human capital level. We then define

$$ICOLLEGE = \frac{\sum_{i=1}^{n} \text{Number of employee with college and above education}_{jsi}}{\sum_{i=1}^{n} \text{Number of employee}_{jsi}}$$

where n is the number of firms in industry s, city j [10]. The range of ICOLLEGE is [0,1].

A major concern is the potential for reverse causality due to the self-selection of external human capital. Higher educated people could move to cleaner cities because they are more sensitive to environmental quality. Due to the existence of rigid "Hukou" system, labor in China is

[10] $ICOLLEGE_{js}$ is computed from the National Bureau of Statistics (NSB) Enterprise Database since our sample is not big enough for computing the industry average level of human capital level.

not as mobile as that in other countries in the world, but still China has witnessed tremendous internal labor migration since the reform of the "Hukou" system was implemented. Thus, we cannot rule out this endogenous problem. To address this potential endogeneity, we introduce average number of books per person in public libraries (BOOK) and number of universities and colleges (UNIVERSITY) in each city as two instrumental variables for CCOLLEGE. These two instruments can be used as proxies for the human capital stock of cities but are intuitively unlikely to be direct determinants of environmental compliance.

Besides the possible endogeneity caused by human capital, another potential problem arises if the degree of environmental compliance is the joint result of government regulation and firm initiatives as shown by Yang and Yao (2012) and Wang and Wheeler (2005). For example, if a firm violates an environmental regulation or causes an environmental accident, the firm not only has to pay fines and penalties, but may suffer from a loss of trust and reputation or a boycott of goods. Such risks have negative effects on the evaluation of a firm's future profits. On the other hand, a firm that actively addresses environmental issues might gain positive reputation among some stakeholders and may influence them to expect that the firm will succeed in reducing environmental risks and production costs in the long term. As a result, better financial performance could be a result of better environmental performance. By using the same strategy of instrument selection, we take industrial-location average ROA as instrumental variable for firm-level financial performance. Industrial-location average of ROA is defined as $IROA_{js} = \frac{\sum_{i=1}^{n} Profit_{jsi}}{\sum_{i=1}^{n} Asset_{jsi}}$, where n is the number of firms in industry s, city j. [11]

3.4. Estimation Results

3.4.1 Case of the full sample

Table 3.4 presents the estimated coefficients and their associated standard errors (SEs) of the ordered probit model as well as conditional mixed process model (ordered probit model with instrument adjustment). As a test of identification, besides the ICOLLEGE and IROA, we include two industry-location averages as additional instrument variables. Since the intangible assets (knowledge and skills) are embodied in the firm's employees and the main factor of it is human capital, the first variable we include is percentage of total assets represented by intangible assets

[11] $IROA_{js}$ is computed from the National Bureau of Statistics (NSB) Enterprise Database.

intensity (INTANG) calculated as the ratio of intangible assets to total assets. The second variable is fixed assets divided by total sales (FIXSALE) which aims to measure a firms' efficiency in terms of amount of fixed asset needed to produce a unit of sale. This variable should affect (negatively) the financial performance, but not, at least, intuitively the environmental performance of firms. In regression (2), Table 3.4, we add six instrumental variables in the ordered-probit specification. The coefficients on FCOLLEGE, CCOLLEGE and ROA become larger in absolute values, while the extents of all instrumental controls enter insignificantly. In regression (3), we instead add these six control variables as instruments. To the extent that our instrumental variables have no direct effect on firms' environmental performance as suggest in (regression (2)) and since they influence to what extent firms are through FCOLLEGE, CCOLLEGE and ROA, they are valid instruments. Adding these additional instruments has the advantage that the model is now over-identified and that the validity of the instruments can be tested. We present some tests results to indicate the quality and validity of the instrument variables used. The instruments perform well. The F-statistics of their joint significance are 77.60, 57.70 and 37.76 respectively and are highly significant. Moreover, we conduct an over-identification test by means of Hansen's J statistic. Our instrumental variables are all significantly correlated with the instrumented variables. As the p-value of Hansen's J statistic is 0.574, we cannot reject the joint null hypothesis that the instruments are valid instruments. These tests provide support for the validity of our instruments.

Most of the coefficients show both the expected signs and high significance. The first point to note is that high human capital contributes to firms' environmental performance both from the interior and the exterior. As it can be seen from Table 3.4, FCOLLEGE and CCOLLEGE are positively associated with firms' environmental performance, implying that a firm with more college (and above) educated employees is more likely to better comply with environmental regulations and a firm located in a city with more college (and above) population tend to have better environmental performance. Our estimates of low human capital variables (FPRIMARY and CPRIMARY) are consistently negatively associated with firms' environmental compliance. For the senior school educated (FSENIOR and CSENIOR), it has a significantly positive internal effect pushing firms to do better compliance while the external effect is insignificant. Comparing the differences across education groups in their susceptibilities to environmental condition, our interaction terms show that greater sensitivities are associated with better compliance of firms located in the cities with a higher share of college (and above) educated population and a lower share of primary school educated population, reflecting that regulatory pressure could differ across cities due to the different educational level of the population.

Table 3. 4 Estimates for ordered probit environmental compliance model (full sample)

Variable	OPROBIT (1)		OPROBIT (2)		IV OPROBIT (3)	
	COEF	SE	COEF	SE	COEF	SE
FCOLLEGE	1.761***	0.627	1.819***	0.636	1.844***	0.649
FSENIOR	1.624*	0.868	1.634*	0.979	1.674*	0.985
FPRIMARY	-1.594**	0.715	-1.609***	0.638	-1.645**	0.758
CCOLLEGE	1.723***	0.692	1.900***	0.531	2.027***	0.596
CSENIOR	0.828	0.579	0.880	0.778	0.863	0.599
CPRIMARY	-0.941**	1.365	-1.017**	0.433	-1.038**	0.465
AIRCOLLEGE	1.295***	0.445	1.296**	0.535	1.295**	0.553
AIRSENIOR	1.377	0.924	1.438	1.006	1.423	1.039
AIRPRIMARY	-0.574**	0.243	-0.586**	0.277	-0.580**	0.248
Export	0.186**	0.091	0.196**	0.099	0.205**	0.099
RD	1.125***	0.391	1.095***	0.388	1.106***	0.390
SIZE	0.032	0.027	0.035	0.023	0.055	0.027
AGE	-0.013	0.027	-0.011	0.021	-0.014	0.027
ROA	0.534***	0.240	0.538**	0.239	0.543***	0.208
FDI	0.340***	0.121	0.340***	0.122	0.341***	0.120
Collective	-0.071	0.140	-0.110	0.137	-0.109	0.140
HMT	0.069	0.121	0.069	0.140	0.066	0.129
Limited	-0.031	0.107	-0.033	0.108	-0.032	0.107
Private	0.016	0.063	0.015	0.067	0.021	0.104
SOE	-0.011	0.034	-0.012	0.034	-0.021	0.032
AIRquality	1.722**	0.742	1.800**	0.776	1.755**	0.787
UNEMP	-2.114***	0.436	-2.053***	0.341	-2.107***	0.392
INTso2	-0.276**	0.115	-0.283**	0.133	-0.274**	0.129
INTwater	-0.059	0.071	-0.055	0.071	-0.054	0.071
INTsoot	-0.261**	0.118	-0.263**	0.120	-0.268**	0.118
MARKET	-0.166	0.192	-0.155	0.172	-0.164	0.190
GDPcap	0.015***	0.003	0.013***	0.003	0.015***	0.003
POPdensity	0.185	0.153	0.192	0.154	0.194	0.157
WEST	-1.047**	0.528	-1.040**	0.512	-1.062**	0.481
EAST	0.584	0.453	0.573	0.424	0.599	0.474
ICOLLEGE			0.084	0.384		
IINTANG			0.386	1.061		
BOOK			0.072	0.080		
UNIVERSITY			0.098	0.147		
IROA			1.263	1.025		
IFIXSALE			-0.015	0.028		

Table 3.4 Continued

Variable		OPROBIT (1)		OPROBIT (2)		IV OPROBIT (3)	
		COEF	SE	COEF	SE	COEF	SE
Instrumentation step							
FCOLLEGE							
	ICOLLEGE					0.854***	0.327
	IINTANG					0.130*	0.074
CCOLLEGE							
	BOOK					0.025***	0.008
	UNIVERSITY					0.002***	0.0006
ROA							
	IROA					0.636***	0.253
	IFIXSALE					-0.041**	0.022
Log-likelihood		-1856.653		-1850.212		2187.235	
LR chi2		493.38		495.13			
Prob > chi2		0.000		0.000		0.000	
Pseudo-R^2		0.197		0.199			
Wald Chi2						612.30	
F-test of instruments (in FCOLLEGE regression)						77.60	{0.000}
F-test of instruments (in CCOLLEGE regression)						57.70	{0.000}
F-test of instruments (in ROA regression)						37.76	{0.000}
Hansen J-statistics						1.970	{0.574}
Observations		2554		2554		2554	

a. *Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.
b. Heteroskedasticity-robust standard errors reported.
c. All regressions allow for clustering by location-industry.
d. F-test on instruments is the test statistics on the F-test of the joint significance of the instruments (ICOLLEGE, IROA, BOOK, UNIVERSITY, IINTANG and IFIXSALE), with p-values in braces. Hansen J-statistics is the test statistic on the overidentification test of instruments, with p-values in braces.
e. To account for the endogenous problems, a three-equation instrumental variables version of the ordered probit model is estimated, utilizing the CMP package for STATA 12.1.

With regard to firm characteristics, results in Table 3.4 present that R&D expenditure per unit of sales (RD) is consistently positive, suggesting that firms that invest in innovation are more likely to observe environmental regulations. The value of exports per unit of sales (Export), one of the proxies for firms' international linkage, is found to be a positive determinant of firms' environmental performance and the effect is significant. The positive coefficient on Export is in line with Christmann and Taylor (2001), who show the evidence that export-oriented Chinese firms are more likely to adopt ISO 14001 certification to control for emissions. A similar finding has been reported in Galdeano-Gómez (2010), where it is argued that an export-oriented firm has a better environmental performance in the Spanish food industry. The ownership dummies show that, consistent with the results of a positive foreign ownership effect from most of the empirical literature, being a foreign firm or foreign related firm increases the probability of compliance with environmental regulations. In terms of other type of ownership, none are found to be statistically significant. Finally, return on assets (ROA) which is instrumented by industry-location IROA is consistently positive and significant. It implies that firms with better financial performance tend to more likely to have better environmental performance.

Turning to the industrial characteristics variables, the pollution intensive variables suggest that firms in pollution intensive sectors are more likely to violate SO_2-related regulations and soot-related regulations although they do not perform significantly worse in polluted water related compliance. Wang and Wheeler (2005) argue that China's water concentration standards are more stringent than its air concentration standards and water emission is targeted by more frequently inspections which induces firms to compliance. On the other hand, the abatement technology of industrial waste water is a relative common practice in some pollution intensive sectors, which induces firms to comply with the standards of acceptable compliance.

In terms of city control variables, we have the following observations. First, firms located in cities with good air quality (AIRquality) are significantly less likely to violate environmental regulations. Firms in cities with higher unemployment ratio (UNEMP) are significant more likely to be non-compliant. This finding supports the argument in Cole et al. (2008b) that a high unemployment rate may make the local government tolerate the existence of a polluting plant nearby if it provides employment. Finally, our regional variables show that, compared to the reference group (firms located in central part of China), being located in the west increases the probability of observing a non-compliant outcome, whereas being located in the east is insignificant.

3.4.2 Case of Clean and Dirty industrial sectors

To gauge the relationship between the dirtiness of an industry and its environmental performance, we divide our sample into six subsets of dirty and relatively clean industrial sectors with respect to polluted water intensive sectors, SO_2 intensive sectors and soot intensive sectors. Following the classification criterion for defining industries as pollution-intensive industries suggested by Mani and Wheeler (1998), we rank the industrial sectors on the basis of actual emission intensity (emission per unit of industrial value-added) by using the data of the 2004 Environmental Statistics Yearbook for conventional water pollutants, SO_2 and soot emissions and the 2004 Industrial

Statistics Yearbook for the industrial value added of each sector. By considering the magnitude of sectoral pollution intensities simultaneously, we pick the 6 dirtiest polluted water-intensive sectors, the 13 dirtiest SO_2-intensive sectors and the 5 dirtiest soot-intensive sectors as the dirtiest industrial sectors. The rest are considered as relatively clean sectors (Table A3.5).

Table 5 reports the results in the case of clean and dirty industries. Our estimation is robust since the sign and significance of the coefficients of three pollutants are almost similar to those in the case of full example in Table 3.4. The Hansen's J test results of overidentifying restrictions reject the exogeneity assumption for the sub-sample of water-related and soot-related clean industries, but fail to reject it for other sub-samples. In either case, the test results are only suggestive due to the potentially limited power of the test.

One difference between the full sample and that involving dirty and clean industrial sectors is that the internal effect of high human capital (FCOLLEGE) is insignificant in clean sectors of category SO_2 and soot. On the other hand, internal human capital plays an important role in environmental performance of firms in dirty industries. For clean industries, the impact of human capital on environmental compliance is mainly explained by the external effect. It is possible that those clean sectors generate considerably less industrial SO_2 and soot emissions than the relative dirty sectors. In this case, high human capital may not play a notable role in pollution abatement. Besides, we can observe that in those SO_2- and soot-related dirty sectors, firms with international linkage via foreign ownership or export-oriented show better compliance with environmental regulatory standards than firms with no international linkage.

Table 3. 5 Estimates for IV-ordered probit model (clean and dirty industries)

Variables	WATER				SO_2				SOOT			
	Dirty		Clean		Dirty		Clean		Dirty		Clean	
	COEF	SE	COEF	SE	COEF	SE	COEF	SE	COEF	SE	COEF	SE
FCOLLEGE	1.691***	0.509	1.051*	0.629	1.464**	0.618	1.744	1.112	2.907***	0.878	2.118	1.375
FSENIOR	1.730**	0.983	0.568*	0.342	0.286	0.192	0.306	0.251	0.500	0.318	0.287	0.263
FPRIMARY	-0.439*	0.199	-1.629**	0.657	-1.124**	0.504	-1.130**	0.533	-0.503*	0.301	-1.330*	0.747
CCOLLEGE	0.787***	0.623	1.027**	0.450	1.640**	0.867	1.698***	0.326	1.355***	1.497	1.529***	0.573
CSENIOR	1.450	1.421	1.614	1.681	1.465	1.423	1.592	1.294	1.431	1.154	1.245	1.020
CPRIMARY	-0.937**	0.386	-1.200**	0.476	-0.562**	0.254	-0.712*	0.398	-0.821**	0.417	-0.726**	0.361
AIRCOLLEGE	1.183**	0.477	1.520**	0.613	1.335**	0.578	1.437**	0.591	1.563**	0.588	1.897**	0.781
AIRSENIOR	1.366	1.339	0.622	0.506	1.942	1.867	2.112	1.371	1.186	0.775	0.266	0.182
AIRPRIMARY	-0.617**	0.305	-1.282**	0.509	-0.514**	0.236	-0.721*	0.410	-0.425*	0.230	-0.676**	0.336
Export	0.679***	0.261	0.484***	0.126	0.892**	0.361	0.337	0.215	0.461**	0.231	0.278	0.193
RD	1.308***	0.505	1.296***	0.431	0.991***	0.274	1.306***	0.507	1.226**	0.619	1.525***	0.442
SIZE	0.056	0.042	0.038	0.032	0.019	0.038	0.067*	0.033	0.014	0.067	0.065**	0.027
AGE	-0.017	0.041	-0.018	0.049	-0.022	0.041	-0.014	0.041	-0.044	0.079	0.026	0.029
ROA	1.587**	0.718	0.387*	0.226	1.691***	0.587	0.410**	0.207	1.546*	0.840	0.855***	0.314
FDI	0.704***	0.203	0.162**	0.081	0.525***	0.182	0.267	0.168	0.285**	0.114	0.440	0.277
Collective	-0.130	0.195	-0.236	0.184	-0.107	0.191	-0.113	0.204	-0.109	0.323	-0.063	0.144
HMT	0.101	0.193	0.138	0.154	0.059	0.167	-0.064	0.167	-0.267	0.287	0.117	0.121
Limited	-0.094	0.167	-0.119	0.137	0.064	0.179	-0.132	0.156	-0.171	0.238	0.033	0.125
Private	0.157	0.169	-0.054	0.133	0.261	0.149	-0.097	0.133	-0.122	0.257	0.124	0.119
SOE	-0.041	0.087	-0.160	0.160	-0.169	0.154	-0.189	0.142	0.208	0.305	-0.053	0.152
AIRquality	2.658**	1.136	1.204	0.747	2.863***	0.786	3.787**	1.565	2.906**	1.378	2.674**	1.151
UNEMP	-2.734***	0.795	-1.920***	0.475	-2.905***	0.499	-1.832***	0.481	-3.651***	1.055	-2.113***	0.392
MARKET	-0.233	0.184	-0.146	0.121	-0.177	0.172	-0.295	0.284	-0.011	0.041	-0.154*	0.083
GDPcap	0.016***	0.005	0.015***	0.004	0.014***	0.004	0.014**	0.004	0.020**	0.009	0.012***	0.003
POPdensity	0.234	0.177	0.067	0.142	0.085	0.059	0.190	0.202	0.184	0.124	0.174*	0.098
WEST	-1.433**	0.618	-0.869	0.572	-0.699**	0.363	-1.697***	0.461	-1.049*	0.624	-1.403	0.899
EAST	0.448	0.452	0.515	0.510	0.471	0.304	0.474	0.484	0.456	0.486	0.660	0.526

a. *Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.

b. All regressions allow for clustering by location-industry.

c. Heteroskedasticity-robust standard errors reported.

d. To account for the endogenous problems, a three-equation instrumental variables version of the ordered probit model is estimated, utilizing the CMP package for STATA 12.1.

e. F-test on instruments is the test statistics on the F-test of the joint significance of the instruments (ICOLLEGE, IROA, IINTANG and IFIXSALE), with p-values in braces. Hansen J-statistics is the test statistic on the overidentification test of instruments, with p-values in braces.

Table 3.5 continued

Variables		WATER				SO_2				SOOT			
		Dirty		Clean		Dirty		Clean		Dirty		Clean	
		COEF	SE	COEF	SE	COEF	SE	COEF	SE	COEF	SE	COEF	SE
Instrumentation step													
FCOLLEGE													
	ICOLLEGE	0.788***	0.261	0.789**	0.396	0.841***	0.164	0.870***	0.245	0.850***	0.259	0.883***	0.167
	IINTANG	0.491*	0.274	0.202*	0.115	0.501**	0.237	0.184*	0.107	0.518*	0.282	0.396***	0.147
CCOLLEGE													
	BOOK	0.030**	0.012	0.025***	0.008	0.022***	0.005	0.027***	0.009	0.021***	0.007	0.026***	0.009
	UNIVERSITY	0.003***	0.001	0.004***	0.001	0.004***	0.001	0.005**	0.002	0.003**	0.0015	0.002**	0.001
ROA													
	IROA	0.583***	0.087	0.677***	0.169	0.476***	0.091	0.802***	0.227	0.441***	0.114	0.675***	0.086
	IFIXSALE	-0.176**	0.097	-0.048**	0.025	-0.057***	0.017	-0.104*	0.057	-0.094**	0.047	-0.114**	0.053
Log-likelihood		575.64		852.012		566.510		852.895		369.336		944.792	
Prob > chi2		0.000		0.000		0.000		0.000		0.000		0.000	
Wald Chi2		243.99		195.74		264.33		329.98		136.20		288.49	
F-test of instruments (in FCOLLEGE regression)		86.32	{0.000}	67.33	{0.000}	56.34	{0.000}	85.13	{0.000}	62.19	{0.000}	96.49	{0.000}
F-test of instruments (in CCOLLEGE regression)		32.97	{0.000}	40.96	{0.000}	29.71	{0.000}	43.91	{0.000}	18.71	{0.000}	66.13	{0.000}
F-test of instruments (in ROA regression)		22.40	{0.000}	50.55	{0.002}	26.60	{0.000}	48.57	{0.000}	19.94	{0.000}	57.81	{0.000}
Hansen J-statistics		2.176	{0.542}	1.715	{0.016}	1.985	{0.483}	2.627	{0.569}	1.736	{0.512}	3.742	{0.037}
Observations		835		1719		1023		1531		436		2118	

a. *Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.

b. All regressions allow for clustering by location-industry.

c. Heteroskedasticity-robust standard errors reported.

d. To account for the endogenous problems, a three-equation instrumental variables version of the ordered probit model is estimated, utilizing the CMP package for the STATA 12.1.

e. F-test on instruments is the test statistics on the F-test of the joint significance of the instruments (ICOLLEGE, IROA, IINTANG and IFIXSALE), with p-values in braces. Hansen J-statistics is the test statistic on the overidentification test of instruments, with p-values in braces.

3.4.3 Marginal and interaction effects

Neither the signs nor the magnitudes of the coefficients are directly interpretable in the ordered probit model. It is necessary to compute partial effects or something similar to interpret the model meaningfully. As mentioned by Mallick (2009) the marginal effect of a variable that is interacted with another variable differs from the marginal effect of a variable that is not interacted with any variable. Hence a direct application of the standard software (such as STATA 12) might lead to incorrect estimates of the magnitude and standard error of the interaction term in nonlinear models. Follow Mallick (2009), we calculate the consistent ordered probit marginal effects as well as interaction effects for interaction terms by assuming that the effects are evaluated at the mean values of repressors as shown in Table 3.6 and Table 3.7. [12]

Table 3.6 depicts marginal effects for an ordered probit of the estimation of environmental performances of industrial firms. It shows the implied effect of explanatory variables, and the associated standard errors of the marginal effect, on the probabilities of all three environmental behaviors. The positive effect of COLLEGE in Table 3.4 translates into positive marginal effects for over-compliance and compliance but negative effect for the non-compliant firms, all of which are statistically significant (Table 3.6). In particular, a 10% rise in FCOLLEGE increases the probabilities of over-compliance and compliance with environmental regulations by 0.046 and 0.026 respectively, and so decreases the probability of non-compliance by 0.071. The marginal increase in FSENIOR only increases the probability of compliance by 23.5% but this effect is just weakly significant at the 10% significant level. When the education level of employees becomes lower, a marginal increase in FPRIMARY decreases the probabilities of over-compliance and compliance by 40.7% and 23.1% respectively and so for non-compliance the probability increases by 63.7%. In terms of the external effect of human capital, we can find a marginal increase in the share of college educated population (CCOLLEGE) leads to an increase in the probabilities of over-compliance and compliance by 0.257 and 0.145 respectively, so decreases the probability of non-compliance by almost 0.402. When it comes to the share of primary school educated population, the result is the opposite. The marginal effects of CPRIMARY on the probability of over-compliance, compliance and non-compliance are -0.119, -0.067 and 0.187 respectively. However, we cannot

[12] The marginal and interaction effects have different signs for different observations, this issue can be avoided by assuming that the effect are evaluated at the mean value of explanatory variables (Ai and Norton, 2003)

find significant marginal effect of external senior school educated population on environmental performance of firms.

Table 3. 6 Marginal effects for firms' environmental compliance

Variables	Over-compliance		Compliance		Non-compliance	
	ME	SE	ME	SE	ME	SE
FCOLLEGE	0.456***	0.155	0.258***	0.100	-0.714***	0.198
FSENIOR	0.414	0.257	0.235*	0.139	-0.648	0.400
FPRIMARY	-0.407**	0.182	-0.231**	0.104	0.637**	0.286
CCOLLEGE	0.257***	0.046	0.145***	0.026	-0.402***	0.071
CSENIOR	-0.334	0.301	0.213	0.192	0.121	0.110
CPRIMARY	-0.119**	0.053	-0.067**	0.031	0.187**	0.085
Export	0.048*	0.025	0.027*	0.014	-0.076**	0.039
RD	0.429***	0.153	-0.274***	0.100	-0.155***	0.057
SIZE	0.022	0.014	-0.014	0.009	-0.008	0.005
AGE	-0.005	0.010	0.003	0.007	0.002	0.004
ROA	0.090**	0.041	0.051**	0.023	-0.140**	0.065
FDI	0.087***	0.031	0.041***	0.014	-0.127***	0.043
Collective	-0.043	0.055	0.026	0.033	0.016	0.023
HMT	0.016	0.029	0.010	0.018	-0.026	0.047
Limited	-0.013	0.042	0.008	0.027	0.005	0.015
Private	0.008	0.039	-0.005	0.026	-0.003	0.014
SOE	-0.008	0.051	0.005	0.033	0.003	0.019
AIRquality	0.434**	0.205	0.246*	0.128	-0.680*	0.354
UNEMP	-0.104***	0.027	-0.059***	0.015	0.163***	0.041
INTso2	-0.106**	0.046	0.068**	0.032	0.038*	0.020
INTwater	-0.013	0.015	-0.008	0.009	0.021	0.022
INTsoot	-0.103**	0.044	0.066*	0.034	0.037*	0.019
MARKET	-0.064	0.051	0.041	0.044	0.023	0.025
GDPcap	0.004***	0.001	0.002***	0.001	-0.006***	0.001
POPdensity	0.047	0.039	0.027	0.023	-0.074	0.060
WEST	-0.397*	0.225	0.139	0.090	0.258*	0.131
EAST	0.118	0.115	0.117	0.120	-0.235	0.220

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

ME: Marginal effect on probabilities averaged over all observations; SE, standard error of the ME

Marginal effects are calculated at the sample means according to Mallick (2009). Standard errors are calculated with the delta method. MEs are calculated based on the results of conditional mixed process (CMP) regression.

As for other firm level characteristics, we find that compliance probabilities are also significantly related to international linkage variables. Looking at the effects of export, Table 3.6 shows that, on average, an export-oriented firm is more likely to be over-compliant and compliant. A 10% increase in export increases the probabilities of over-compliance by 5 percentage points. In terms of ownership, Table 3.7 indicates that, relative to the reference group of public firms, firms with foreign ownership are 8.7% and 4.1% respectively, more likely to be over-compliant and compliant group, and 12.7% less likely to compliance with environmental regulations. A marginal increase in R&D expenditure increases the probability of being over-compliant by 0.429 while probabilities for compliance and non-compliance decrease 0.274 and 0.155 respectively. A possible explanation for the result that R&D expenditure is negatively associated with firms' compliance behavior is the following. Those firms (that are in compliance) which have more expenditure on R&D may cut the budget on investment in pollution abatement and treatment. A further firm-internal factor that is significantly associated with environmental behavior of firms is ROA. A marginal increase in ROA increases the probabilities of being over-compliant and compliant by 0.09 and 0.05 respectively and so decreases the probability of non-compliance by 0.14.

Turning to the sector characteristics, Table 3.6 indicates that, firms in SO_2-intensive and soot-intensive industries are less likely to be over-compliant but they are more likely to be compliant and non-compliant. For firms in SO_2-intensive industries, other explanatory factors being equal, they are 10.6% less likely to be over-compliant but more likely to be compliant and non-compliant by 6.8% and 3.8% respectively. Being included in soot-intensive industries, on average, decreases the probabilities of over-compliance by 10.3% but increases the probabilities of compliance and non-compliance by 6.6% and 3.7% respectively.

In terms of our city and regional characteristics included in the model, we find that being located in cities with higher income and lower unemployment ratio, firms tend to be more likely to over-comply and comply with environmental regulations. Firms located in high unemployment cities have a higher chance of being in the non-compliant group. A 10% increase in unemployment ratio of a city increases the probability of infringing environmental regulations by 1.63% for firms in this city. Other factors being equal, 1 unit increase in GDP per capita of cities increases the probabilities of over-compliance and compliance by 0.4% and 0.2% respectively for firms located in those cities, and so decreases the probability of non-compliance by 0.6%. A marginal increase in the ratio of days with good air quality within one year increases the probabilities of being over-compliant and compliant by 0.434 and 0.246 respectively. For other regional dummies, on average, being located in the west decreases the probability of over-compliance and increases the probability of non-compliance, but the probability of compliance does not seem to be much related to the western location dummy.

The interaction effects as shown in Table 3.7 suggest that college educated population are more sensitive to environmental quality and are likely to impose greater pressure on the stringency of regulations to impel firm over-comply and comply with environmental regulations. While the primary school and below educated group is more likely to induce government to relax the environmental regulation, resulting in environmental non-compliance. As for senior school educated population, they are not more sensitive to environmental quality as compared to the reference group (the junior school educated population).

Table 3. 7 Magnitudes of the interaction effects

Interaction	Over-compliance		Compliance		Non-compliance	
	IE	SE	IE	SE	IE	SE
AIRCOLLEGE	2.089***	0.711	1.184***	0.440	-3.273***	1.133
AIRSENIOR	1.173	0.747	0.665	0.398	-1.838	1.178
AIRPRIMARY	-1.432**	0.642	-0.812**	0.374	2.244**	1.025

*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.
IE: Interaction effect on probabilities averaged over all observations; SE, standard error of the IE
Magnitudes of the interaction terms are obtained according to Mallick (2009). Standard errors are calculated with the delta method. MEs are calculated based on the results of conditional mixed process (CMP) regression.

3.5 Concluding Remarks

In this paper, we have empirically examined the internal and external effects of human capital on environmental compliance by using the real environmental performance data of Chinese industrial firms. Our estimation shows that firms' compliance decisions are not only affected by their internal endowment of human capital, but also impacted by the external stock of social human capital. Firms with high human capital are more likely to have better environmental compliance. The study also finds that a highly educated local population (CCOLLEGE) contributes to firms' environmental performance. In contrast, a low level of education in the local population (CPRIMARY) is associated with poorer compliance. The results are still significant after we give thought to the possible endogeneity of both internal and external human capital. However, for clean industries, our results demonstrate that the variation in external human capital is a better determinant of the firms' environmental performances than the variation in internal human capital. We do not find supporting evidence for the internal effect of human capital in SO_2- related and soot-related clean industries when we decompose our data into dirty and clean sectors by pollution intensity of industries in the terms of industrial polluted water emission, industrial SO_2 emission and industrial soot emission.

The findings in this study have important policy implications. The role of city-wide human capital levels in compliance suggests that there is a positive externality from education. More generally, evidence from this study suggests that the situation of weak implementation of environmental supervision and evasion of environmental monitoring could be improved by means of internal and external human capital. On the regulator side, a strategy of boosting the educational attainment of the population may be recommended to pull firms into better environmental compliance. On the firm side, raising human capital may induce improved environmental performance.

Although we have established the importance for compliance of external human capital, we do not know the exact route by which higher education levels influence firm behavior. It could be that human capital levels in the regulatory agency track general education level and so city-level human capital is a proxy for the human capital of the environmental agency. Alternatively, it could be that individuals with higher education levels are more sensitive to compliance and/or more efficient in making complaints, lobbying for controls and prompting investigations into compliance. This is an issue that requires further research.

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Appendix

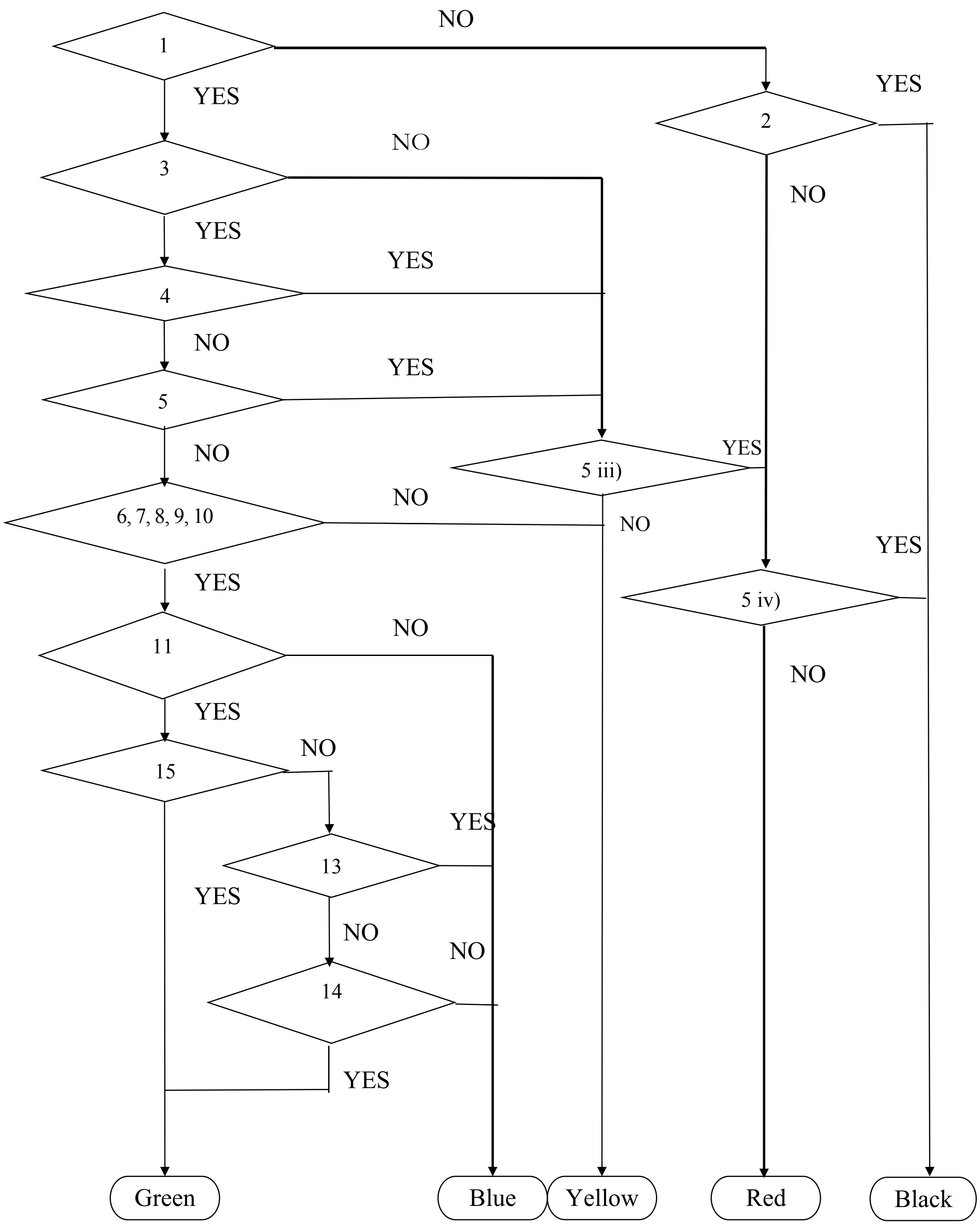
Table A3. 1 Indicators Assessing Firm Environmental Behavior

No.	Indicator	Note
1	Emission compliance	The rate of emission compliance of major controlled pollutants from all outlets should be greater than and equal to 80% or the average concentration of major controlled pollutants should comply with relevant emission standards. The rate of disposal/utilization of hazardous wastes should be 100%.
2	Repeated occurrence of environmental non-compliance	The ratio of non-compliance to the frequency of environmental inspection and monitoring is greater or equal to 50%.
3	Total volume control	-Firm which holds pollutant discharge permit should comply with the requirements of the permit. -Firm which do not have pollutant discharge permit should comply with emission standards.
4	Administrative penalty	Firm has one or more records of non-compliance according to on-site environmental inspection.
5	Environmental pollution accident	i) General accident: once or more times occurrence of pollution accident with direct economic loss over 1 000 RMB and lower than 10 000 RMB. ii) Serious accident (at least one of the following four situations): -Direct economic loss caused by the accident is greater than 10 000 RMB and lower than 50 000 RMB; -Poisoning symptom occurred; -Conflicts among citizens and the firm caused by the accident -The accident causes environmental damage. iii) More serious accident (at least one of the following situations) -Direct economic loss caused by the accident is greater than 50 000 RMB and lower than 100 000 RMB; -The poisoning occurred leads to potential permanent disability; iv) The most serious accident: direct economic loss caused by the accident is greater than 100 000 RMB.
6	On-time payment of pollution levy	Firm pays for pollution levy on time in at least 70% of twelve months of a year and pays for pollution levy within 2 months in the left months of a year.
7	On-time reporting of emissions	Firm finishes annual reporting of emissions on time. The Firm, which holds pollutant discharge permit, reports its monthly emissions on time.
8	Standardized emission outlet	-The emission outlets should be checked and accepted by EPB if the Firm has the liability of pollution abatement. -The emission outlets if not specified should be standardized.
9	Implementation of the System of "Three Synchronous Requirements" and environmental management procedure for construction projects	-Firm should conduct environmental protection preliminary hearing on time when it proposes a project. -Firm should conduct environmental impact assessment on time when it conducts a feasibility study. -Firm complies with the requirements defined by Regulation of Environmental Management of Construction Project.
10	Environmental organization Environmental protection staff Environmental management system	Firm has environmental organization. Firm has full-time or part-time environmental protection staff. Firm has corporate environmental management systems to fulfill corporate environmental management task.

Table A3.1 Continued

No.	Indicator	Note
11	Comprehensive utilization rate of industrial solid wastes greater than or equal to 80%	Disposal rate of industrial solid wastes should be 100% and the comprehensive utilization rate of industrial solid wastes greater than or equal to 80%.
12	Repeated occurrence of public complains	The municipal government receives more three times of public complains and corporate environmental performance causes certain environmental impacts and damage.
13	Occurrence of public complain	The municipal government receives once public complain and corporate environmental performance causes certain environmental impacts.
14	Cleaner production	Firm passes cleaner production audit and corporate environmental management reaches domestic top level and advanced international level.
15	ISO 14000 certification	Firm passes ISO 14000 certification and gains certificate.

Figure A1 Conceptual Scheme of the Grading System



Note: 1,2,3,4,5,6,7,8,9,10,11,13,14,15 represent 15 indicators assessing firms' environmental performances in Table A1.

Table A3. 2 Information of dropped data

CITY	Green	Blue	Yellow	Red	Black	Total	Percent
Changde	0	1	0	0	0	1	0.1
Changzhou	0	1	1	0	0	2	0.2
Chaohu	1	3	0	0	0	4	0.3
Chongqing	0	2	0	1	0	3	0.3
Hangzhou	19	52	41	2	0	114	9.7
Huaibei	2	9	1	0	0	12	1.0
Huainan	0	7	10	0	0	17	1.4
Huhehot	4	12	7	0	0	23	2.0
Jiaozuo	0	1	2	0	0	3	0.3
Jiayuguan	0	0	0	0	0	0	0.0
Jinan	1	4	3	1	0	9	0.8
Liuzhou	2	16	9	0	0	27	2.3
Maanshan	0	4	3	0	0	7	0.6
Nanjing	37	92	88	9	2	228	19.4
Nantong	7	11	13	0	1	32	2.7
Ningbo	23	102	59	2	0	186	15.8
Suzhou	34	122	102	6	1	265	22.6
Taizhou	4	16	6	1	2	29	2.5
Tongling	7	22	10	3	0	42	3.6
Wenzhou	2	6	4	0	0	12	1.0
Wuxi	8	21	9	4	1	43	3.7
Xuzhou	0	7	7	3	2	19	1.6
Yancheng	2	5	4	1	0	12	1.0
Yangzhou	0	3	8	0	0	11	0.9
Yantai	0	1	1	0	0	2	0.2
Zhenjiang	9	19	17	2	1	48	4.1
Zhuzhou	0	4	4	0	1	9	0.8
Zibo	1	3	8	2	1	15	1.3
Total	163	546	417	37	12	1175	
% of firms in each level	13.9	46.5	35.5	3.1	1.0		

Table A3. 3 Variables and definitions

Variables		Definition	Source
Environmental compliance		=2 if the firm environmental behavior is evaluated as "blue" and "green"; =1 if the firm's environmental behavior is evaluated as "yellow"; =0 otherwise	④
Human capital variables	FCOLLEGE	share of college educated (and above) employees in the firm	①
	FSENIOR	share of employees with senior high school education in the firm	
	FJUNIOR	share of employees with junior high school education in the firm	①
	FPRIMARY	share of employees with primary school education (and below) in the firm	①
	CCOLLEGE	share of college educated (and above) population in the city	⑤
	CSENIOR	share of senior high school educated population in the city	
	CJUNIOR	share of junior high school educated population in the city	⑤
	CPRIMARY	share of primary school educated (and below) population in the city	⑤
Firm-level variables	RD	R&D expenditure/sales	①
	SIZE	the logarithm of the number of employees by the end of the year	①
	Age	The age of the firm	①
	Exports	Total export/total sales	①
	ROA	Earnings before interest and tax EBIT/Total Assets	①
	HMT	Dummy variable,=1 if the firm is registered as joint ventures, cooperative with Hong Kong, Macau, Taiwan investors, or HMT wholly owned companies, or HMT shareholding limited companies; =0, otherwise	①
	FDI	Dummy variable,=1 if the firm is registered as joint ventures, cooperative with foreign investors, or wholly foreign owned companies, or foreign shareholding limited companies; =0, otherwise	①
	SOE	Dummy variable,=1 if the firm is registered as state-owned enterprises, including alliances of SOEs and unlisted state-owned limited companies; =0, otherwise	①
	Collective	Dummy variable, =1 if the firm is registered as collectives or alliances of collectives; =0, otherwise.	①
	Public	Dummy variable, =1 if the firm is a public listed company; =0, otherwise	①
	Limited	Dummy variable,=1 if the firm is registered as unlisted non-state-owned limited companies; =0, otherwise.	①
	Private	Dummy variable,=1 if the firm is registered as private; =0, otherwise.	①
Industry-level variables	INTso2	Industrial SO_2 emission/industrial value added	②③
	INTwater	Industrial waste water emission/industrial value added	②③
	INTsoot	Industrial soot emission/industrial value added	②③
Regional variables	Market	Measurement if marketization of province level from Marketization of China's provinces 2004 report. Higher value indicates Higher entry barrier at province level.	⑥
	Unemployment	Unemployment rate of the city	⑤
	BOOK	Average number of books in public libraries in the city.	
	UNIVERSITY	Number of universities and colleges in the city.	
	AIRquality	Ratio of days with excellent or good air quality in urban areas in one year	②
	POPdensity	Population density	⑤
	WEST	Dummy variable, =1 if the firm is located in the western China; =0, otherwise	⑤
	CENTER	Dummy variable, =1 if the firm is located in the central China; =0, otherwise	⑤
	EAST	Dummy variable, =1 if the firm is located in the eastern China; =0, otherwise	⑤
Interactions	AIRCOLLEGE	Interaction between AIRquality and CCOLLEGE	②⑤
	AIRSENIOR	Interaction between AIRquality and CSENIOR	②⑤
	AIRJUNIOR	Interaction between AIRquality and CJUNIOR	②⑤

Data source:
①China industrial enterprises database (survey data 2005);
②China Environmental Statistics Yearbook (2005);
③China Industrial statistics yearbook (2005);
④EMP Environmental information disclosure system data (2004);
⑤China City Statistical Yearbook (2005);
⑥Marketization of China's provinces 2004 report.

Table A3. 4 Statistical description of the data (2004)

Variable	Unit	Obs.	Mean	Std. Dev.	Min	Max
FCOLLEGE	ratio	2554	0.143	0.160	0.000	1.000
FSENIOR	ratio	2554	0.374	0.220	0.000	1.000
FJUNIOR	ratio	2554	0.483	0.287	0.000	1.000
FPRIMARY	ratio	2554	0.017	0.012	0.000	0.276
CCOLLEGE	ratio	2554	0.061	0.030	0.014	0.117
CSENIOR	ratio	2554	0.132	0.028	0.061	0.243
CJUNIOR	ratio	2554	0.351	0.033	0.295	0.469
CPRIMARY	ratio	2554	0.456	0.048	0.327	0.613
AIRCOLLEGE	CCOLLEGE*AIRquality	2554	0.047	0.025	0.006	0.095
AIRSENIOR	CSENIOR*AIRquality	2554	0.276	0.051	0.147	0.416
AIRJUNIOR	CJUNIOR*AIRquality	2554	0.363	0.083	0.138	0.533
Exports	ratio	2554	0.171	0.307	0.000	1.000
RD	ratio	2554	0.002	0.010	0.000	0.249
SIZE	log form of employment	2554	5.595	1.206	1.792	10.843
AGE	year	2554	1.061	1.152	0.069	19.340
ROA	ratio	2554	0.045	0.108	-1.628	1.108
IROA	ratio	2554	0.049	0.055	-0.240	0.637
FDI	dummy	2554	0.177	0.382	0.000	1.000
Collective	dummy	2554	0.052	0.223	0.000	1.000
HMT	dummy	2554	0.121	0.326	0.000	1.000
Limited	dummy	2554	0.170	0.376	0.000	1.000
Private	dummy	2554	0.330	0.470	0.000	1.000
SOE	dummy	2554	0.070	0.256	0.000	1.000
AIRquality	ratio	2554	0.791	0.136	0.421	0.992
UNEMP	ratio	2554	0.071	0.012	0.026	0.101
INTso2	tonnes per million yuan of value added	2554	0.027	0.046	0.0003	0.235
INTwater	1000 tonnes per million yuan of value added	2554	0.061	0.086	0.002	0.373
INTsoot	tonnes per million yuan of value added	2554	0.035	0.081	0.0003	0.312
MARKET	index	2554	8.400	1.358	3.950	9.770
GDPcap	1000 yuan per capita	2554	35.155	14.561	6.495	57.992
POPdensity	1000 people/sq.km	2554	1.503	1.010	0.095	2.927
BOOK	books per person	2554	0.466	0.369	0.100	2.000
UNIVERSITY	/	2554	11.278	10.866	2.000	58.000
WEST	dummy	2554	0.086	0.265	0.000	1.000
CENTER	dummy	2554	0.172	0.280	0.000	1.000
EAST	dummy	2554	0.742	0.364	0.000	1.000

Table A3. 5 Pollution intensities of industries 2004

Industrial sector	WATER		SO2		SOOT	
	Emission intensity	Rank	Emission intensity	Rank	Emission intensity	Rank
Electric & Heating Power	5938.63	8	23.49	1	8.42	2
Electronic Machinery and Equipment	298.99	32	0.05	34	0.05	33
Apparel, Shoes, and Hat Manufacturing	1007.00	27	0.11	30	0.07	31
Textile	6475.27	6	1.24	15	0.53	18
Mining and Processing of Nonmetal Ores	6136.10	7	2.38	11	6.05	3
Nonmetallic Minerals Products	2097.00	21	7.67	2	31.16	1
Recycling	1522.35	22	0.45	21	0.40	19
Handicraft Article	244.96	34	0.04	35	0.05	32
Mining & Processing of Ferrous Metal Ores	5458.91	10	2.18	12	2.11	11
Smelting and Pressing of Ferrous Metals	4347.55	12	2.64	10	4.08	4
Chemical Fibers	11829.49	4	2.89	8	0.98	16
Chemical Materials & Chemical Products	9466.92	5	3.03	7	1.99	12
Furniture	201.34	35	0.09	31	0.07	30
Transportation Equipment	1170.13	26	0.16	28	0.32	22
Metal Product	1192.70	24	0.24	26	0.19	24
Coal Mining and Washing	2745.22	17	0.84	18	1.50	13
Wood Processing and Product	2358.70	19	1.26	14	2.14	10
Agricultural & By-Product	5337.27	11	0.92	17	1.38	14
Leather, Fur, Feather and Related Products	2333.75	20	0.24	25	0.19	25
Natural Gas Production and Distribution	12898.58	2	4.12	5	2.61	8
Petroleum	3499.49	16	3.87	6	3.54	5
Food Manufacturing	4321.34	13	0.96	16	0.62	17
Production and Distribution of Water	5511.33	9	0.29	23	0.11	28
Plastics	281.01	33	0.12	29	0.09	29
Communication Equipment	303.24	31	0.03	36	0.03	36
General Machinery	892.41	28	0.30	22	0.31	23
Rubber	1271.57	23	0.81	19	0.35	21
Tobacco Products	168.77	36	0.07	32	0.04	34
Medicines	3652.88	15	0.76	20	0.39	20
Stationery and Sporting Goods	1182.39	25	0.23	27	0.11	27
Beverage Manufacturing	3753.42	14	1.27	13	1.10	15
Printing and Recording Media Reproducing	342.81	30	0.05	33	0.04	35
Non-Ferrous Metal Ore Mining	12036.19	3	2.66	9	2.38	9
Smelting & Pressing of Non-ferrous Metals	2565.46	18	5.08	3	2.82	7
Paper and Paper Products	37305.11	1	4.57	4	2.84	6
Special Machinery	855.73	29	0.26	24	0.17	26

Note: pollution intensities are measured as tonnes per million yuan of industrial value added

CHAPTER 4 DEVELOPMENT OF ECO-FIRMS, INDUSTRIAL ENVIRONMENTAL PERFORMANCE AND REGULATION STRINGENCY IN CHINA

4.1 Introduction

China is undergoing rapid industrialization and is becoming one of the world's biggest consumers of natural resources. However, without a comprehensive sustainable development scheme, such industrialization has brought about very serious environmental problems. An assessment by Chinese Research Academy of Environmental Science (CRAES) has identified industrial pollution as the source of approximately 70% of China's total environmental pollution. For many environmental problems, abatement in the form of goods, services and technologies is likely to play a significant role. Abatement services are often produced and developed in a specific industry, so called an "eco-industry" which sells abatement goods, services and technologies to other polluting industries. Unsurprisingly, the eco-industry has then become a major topic for sustainable development and environmental policy discussions. Unlike profit-oriented industrial polluters which are frequently argued to be at the origin of environmental deterioration and resource depletion, the pollution control products and services of eco-firms do not bring only economic benefit but also contribute to environmental compensation and improvement.

The development of eco-firms is determined by both the demand side and the supply side both of which are promoted by environmental regulation through government intervention. It is argued that the improved industrial environmental performance is driven by environmental strategies and policies thorough governmental intervention (Gunningham and Sinclair, 1998). In particular in China, the market demand for environmentally sound technologies, products and services is initialized and shaped by government promotion and industrial environmental performance requirements in China (Liu et al. 2006). We define this effect as the regulation-induced demand effect. In this sense, how the government regulates polluting industry, and to what extent it is successful has major consequences for eco-firms' market demand on industrial point sources. As for the supply side, the environmental policy is likely to affect an eco-firm's output decisions. According to David et al. (2006), eco-firms have such expectation that a stricter environmental policy will reduce the price-elasticity of abatement demand. This acts as a market signal that gives an incentive to eco-firms to adjust their outputs and prices via their exercise of market power, which is defined as market power effect. Since environmental regulation is fundamentally related to the demand for and supply of the eco-firm's products and services, it would be interesting to examine abatement demanders' and suppliers' response to a stricter environmental policy.

The aim of this study is to provide a rigorous examination of the linkage between environmental regulation stringency and the demand for and supply of abatement goods and services. In so doing, we will identify and quantify two distinct mechanisms through which environmental regulation stringency may influence individual abatement output. The first may be labeled the regulation-amplified market power effect and refers to the impact of environmental regulation stringency on an eco-firm's output adjustment via its market power. The second one is the regulation induced demand effect which refers to the regulation induced effect on industrial abatement demand and its consequent impact on the individual abatement output of eco-firms. We construct a five-equation simultaneous model to examine the problem which includes the impact of environmental regulation stringency on both abatement output and industrial abatement volume though various underlying simultaneous mechanisms. This simultaneous system is then tested by the panel data of 679 eco-firms in 78 industrial Chinese cities during the implementation period of Administration on the collection and use of pollution discharge fees (promulgated by the State Council) from 2003 to 2007.

Our contribution is threefold. First, in most of the environmental economics literature, as David and Sinclair-Desgagné (2006) indicate, pollution abatement is generally assumed to be set only by industrial polluters, based in turn on relevant regulatory, technological or output market considerations, but omitting the bilateral relationship with actual suppliers, eco-firms. In this study, we address the environmental regulation effect on individual abatement output of eco-firms. To the best of our knowledge, our empirical study is the first to shift focus from industrial polluters to abatement suppliers, we attempt to fill this gap in this line of research by providing data from Chinese eco-firms.

Second, we quantify the overall effect of environmental regulation stringency on individual abatement supply by clarifying the directions of the market power effect and the regulation induced demand effect. From the full sample analysis, the results show that a stricter environmental policy will increase an eco-firm's output. This is confirmed by the insignificant regulation induced market power effect and the significant greater demand effect. However, when estimating the impact of regulation stringency on individual output of firms in different eco-industrial sectors, a distinction is drawn between eco-firms in the sewage treatment sector and those in other eco-industrial sectors; we find that a stricter environmental policy tends to cause business-stealing effect in sewage treatment sector.

Third, the measurement of environmental regulation is a crucial issue in this line of research. Most previous studies do not take into account the fact that regulatory stringency differs with respect to different kinds of target pollutants due to the different technological difficulties in abatement of different pollutants. With such consideration, we select industrial SO_2 emissions and industrial wastewater emission as two target pollutants and use levy charges of industrial SO_2 and treatment prices of industrial wastewater to measure their corresponding regulation stringency respectively. Hence, the proxies are able to compare the stringency of environmental regulation across cities, even if they differ with respect to different target pollutants. The proxies for policy stringency with respect to different pollutants help us obtain insights and provide implications in terms of different targeted pollutants.

The following section will now briefly review the literature regarding the effect of environmental regulation stringency on abatement supply and demand. Section 3 next presents our theoretical model and its explanation. Section 4 proposes the econometric specification and describes the dataset. Section 5 displays the empirical estimates and discusses the results. The final section contains concluding remarks and policy implication.

4.2 Literature review

There exists a well-developed strand of the environmental economics literature analyzing the strategic application of environmental regulation. The majority of this literature focuses on testing the Porter hypothesis and examining industrial polluters' abatement effort as a response to environmental regulations, in which abatement is assumed to be set only by polluter. Wang (2002) empirically tests the pollution abatement efforts of Chinese industries in response to pollution regulations and the results show that plant-level expenditures on end-of-pipe wastewater treatment are strongly responsive to the pollution charges. The estimated elasticities of operation cost and new investment with respect to pollution price are 65 and 27%, respectively. Supported by the establishment-level data from the US Census Bureau's Pollution Abatement Costs and Expenditures (PACE) survey, Becker (2005) investigate the effects of the Clean Air Act on abatement capital expenditures and operating costs of manufacturing plants. His results show that heavy emitters of the "criteria" air pollutants that were subject to more stringent regulation generally had higher abatement expenditures. Another finding from the literature on the relationship between environmental policy and abatement demand is that the incentive for abatement adoption differs between different environmental instruments. Xepapadeas (1992) examines theoretically the effects of environmental policy in the form of emission charges or emission standards on firm's optimal choices of abatement input and finds that the amount of abatement input depend on the type of environmental policy it faces. Requate and Unold (2003) investigate incentives to adopt advanced abatement technology and show that taxes provide stronger incentives than permits, auctioned and free permits offer identical incentives, and standards may give stronger incentives than permits.

There is no question that the abatement efforts of industrial polluters can be strengthened by tightening environmental regulation. When industrial polluters put effort into abating emission, they have come to largely rely on a growing number of eco-firms for the delivery of abatement goods, services and technologies as indicated by Feess and Muehlheusser (1999), Greaker and Rosendahl (2008), David and Sinclair-Desgagné (2011). Hence, market demand for abatement goods and services is also driven largely by government environmental regulation and enforcement efforts (Feess and Muehlheusser, 2002; UITC, 2005).

Recently, economists have begun to examine the precise relationship between environmental regulations and the market for abatement goods and services. Most of the studies are theoretical models focusing on the eco-industry's contribution to an economy's trade. Baumol (1995) was the first to acknowledge the existence of the eco-industry, he indicated that an eco-industry may contribute to an economy's trade competitiveness and is likely to contribute to a country's relative national income. Feess and Muehlheusser (1999, 2002) integrated the eco-industry into the framework of strategic environmental policy, examine whether tighter environmental regulation may benefit a trade nation by deriving the optimal environmental policy from a national point of view and show that the presence of eco-industry can lead to a national leadership in pollution control.

In the above studies, the regulated eco-industry acts as a policy instrument for pollution control by government; none of them explicitly address the consequence for the eco-industry itself of stringent environmental regulation. This issue was taken up in a recent article by Greaker (2006), who models the abatement sector as consisting of several imperfectly competitive firms. Tighter pollution regulation makes the sector more competitive and lowers markups. He finds conditions under which pollution regulation increases competitiveness between eco-firms. David and Sinclair-Desgagné (2005) consider how different policy instruments-emission tax, emission standards and voluntary agreements can affect the abatement efforts by polluters and the price of abatement goods and services (so the consequent outputs of eco-firms).

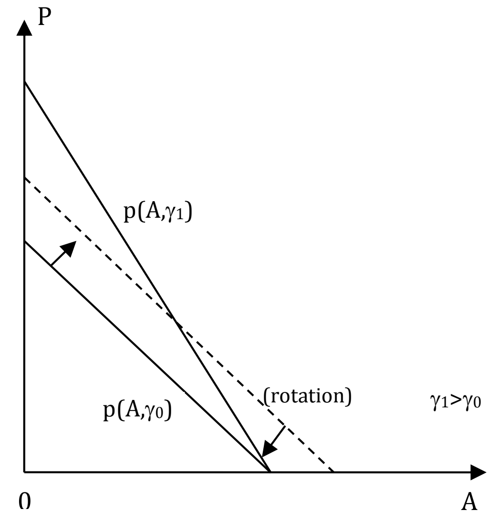


Figure 4.1 Impact of a stricter environmental policy on the abatement demand curve
Source: David, et al (2011)

More recently, David et al. (2011) highlights the specific role of environmental policy in fostering entry in the eco-industry and structuring demand for abatement goods and services. In their study, an eco-industry is assumed to be an oligopolistic industry. The major lessons of their study are summarized in Figure 4.1. In this figure, the horizontal axis shows industry abatement and the vertical axis represents price of abatement services. When the pollution charge is increased (from γ_0 to γ_1), the polluter decreases output while purchasing more abatement goods and services at a given price p. This causes a parallel upwards shift of the inverse demand function. Additionally, a pollution charge rise will lead to a steeper inverse demand function which generates a clockwise rotation of the inverse demand function making industrial polluters becomes less-sensitive to the price of abatement goods and services. According to Hamilton (1999), these two effects on demand, a parallel shift and a rotation, have opposite consequences in an oligopolistic industry with free entry. When apply to the eco-industry, the former enhances the abatement supply whereas the latter tends to lower it through the oligopolistic eco-firms' practice of market power [13]. Thus the final effect of a stricter environmental policy seems ambiguous and we will further examine it empirically.

[13] According to David et, al (2011), the effect of regulation stringency on individual abatement output is depending on the value $p_{AA}p_{\gamma}$-$p_{A}p_{A\gamma}$, where p is the price of abatement goods and services, A is the industrial abatement demand and γ is the stringency of environmental regulation. $p_{AA}p_{\gamma}$ captures the

When estimating the impact of a stricter environmental policy on abatement demand, David et al (2011) point out that the number of eco-firms (m) always goes up (from m_0 to m_1) under a more stringent environmental policy. Figure 4.2 illustrates the aggregate equilibria on the abatement market when the cost of making abatement goods and services is convex. The initial equilibrium output is A_0. When the pollution charge is raised (from γ_0 to γ_1), the marginal revenue curve rotates towards the right due to the rotation of the inverse demand curve and the increase in the number of incumbent eco-firms m ($m_0<m_1$). The marginal cost curve, in contrast, may tilt to the right ($m_1MC_1(A/m_1)$) or to the left ($m_1MC_2(A/m_1)$), as m increases while the individual marginal cost rotates to the right. In all cases, the quantity of abatement goods and services finally delivered A_1 (A_1') is larger than A_0.

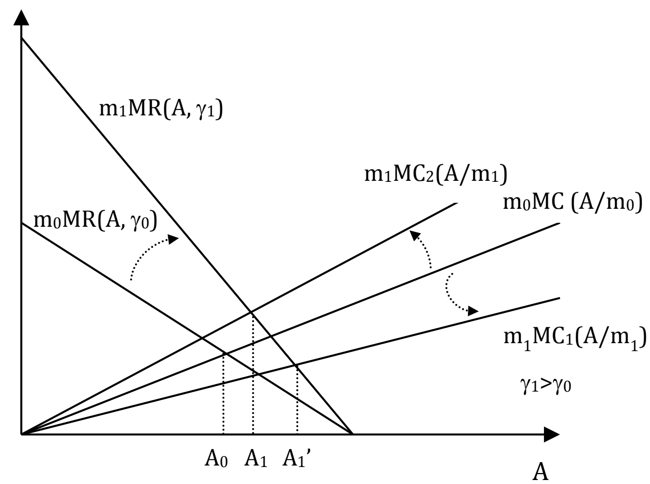


Figure 4.2 the impact of a stricter environmental policy on aggregate equilibria of the abatement market (source: David et al.)

Reviewing the literature, more stringent environmental regulations seem to spur more industrial abatement demand, while has an uncertain influence on an eco-firm's output. In fact, there are two points worth examining with regard to the environmental regulation-an eco-firm's output nexus. One is environmental regulation-induced demand effect. Empirically, the demand effect brought about by a stricter environmental policy has not been adequately examined when

regulation induced demand effect on individual abatement output, the larger p_t, the more the polluter is willing to spend on abatement following a stricter environmental policy. $p_A p_{A\gamma}$ captures the market power of the eco-industrial sectors, the greater $|p_A|$, the greater the eco-industrial sector's market power; the greater $|p_{A\gamma}|$, the stricter the environmental policy amplifies such power. The two effects work in the opposite direction, hence, the net effect of regulation stringency on individual abatement output is depending on which effect dominates.

we taking into account the channels though which environmental regulation stringency can affect abatement demand. For instance, regulation stringency itself can be affected by fast emission growth, local economic growth and so on. Second, to test the net impact of environmental regulation stringency on an eco-firm's output decision, the theoretical model developed by David et al. (2001) serves as a satisfactory approach, while it has not been empirically tested.

4.3 Theoretical foundations: system of simultaneous equations

Following David et al. (2011), we suppose that an eco-firm's output decision can be affected by market power effect and regulation induced demand effect. Then how does regulation stringency affect the local abatement demand? Consider the determinants of industrial abatement (Y_{it}, E_{it}, and γ_{it} as indicated in section 4.3.2) which are assumed to be endogenous variables in our study; we need to identify the complex simultaneous interaction among local abatement demand, local emission scale, local economic growth and local regulatory stringency. We suppose that regulation stringency can affect abatement demand through three channels. Firstly, a stricter environmental policy can directly foster pollution abatement, the stricter the environmental policy, the greater the abatement demand (He, 2006; David et al., 2011). Besides, the indirect impact of regulation stringency on abatement demand is then captured through its influences on emission reduction. We expect that a stricter regulation may contribute to emission reduction, which in turn reduces industrial abatement due to the decreasing amount of industrial emission required to be abated. Furthermore, regulation induced emission growth may affect the growth of the local economy which consequently impact the abatement demand. As described above, the relationship between the environmental regulation stringency and the output of an eco-firm is based on the following five-equation simultaneous system.

$$\begin{aligned}
&x_{jit} = f(A^{L}_{it}, A^{O}_{it}, \gamma_{it}) \\
&A^{L}_{it} = a\left(Y_{it}, E_{it}, \gamma_{it}, HCI_{it}, TECH_{it}\right) \\
&E_{it} = e(Y_{it}, W_{it}, \gamma_{it}) \\
&Y_{it} = y(K_{it}, L_{it}, E_{it}, A^{L}_{it}) \\
&\gamma_{it} = t(E^{net}_{t-1}, Y_{it}, Hedu_{it}, POPden_{it}, UNemp_{it})
\end{aligned} \tag{1}$$

(j: indicator for different eco-firm, i:indictor for different city, t: indicator for different year)

x_{jit}: abatement output value of the eco-firm

A^{L}_{it}: local abatement demand

A^{O}_{it}: outside abatement demand

γ_{it} : environmental regulation stringency

Y_{it}: total real GDP

Ψ_{jit}: vector of firm-level characteristics including a firm's size, R&D expenses, advertisement expenses, export volume, and ownership status

Ω_{it}: industrial capital-labor ratio

K_{it}: total capital stock employed in industrial production

L_{it}: total labor employed in industrial sectors

E_{it}: original industrial emission without abatement

HCI_{it}: industrial human capital intensity

$TECH_{it}$: technological and scientific expenses by local government

E^{net}_{it-1}: lagged emission with abatement

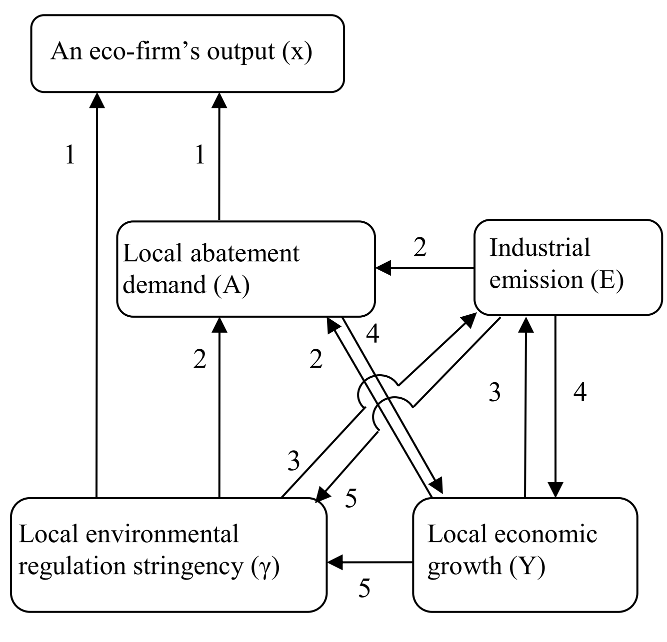
$Hedu_{it}$: city human capital level

$POPden_{it}$: population density

$UNemp_{it}$: unemployment rate

Figure 4.3 summarizes the complex interactions among individual output of eco-firms (x_{jit}) and the four endogenous city-level variables (A_{it}, E_{it}, Y_{it} and γ_{it}) as described in the simultaneous system. It enables us to account for various potential correlations between environmental regulation stringency and abatement supply and demand through the intermediation of the other economic characteristics. The numbers marked besides the arrows correspond to the equation numbers in system (1).

Figure 4. 3 The schema for the linkage between an eco-firm's output and regulation stringency



4.3.1 Abatement output

The abatement output equation describes the determinants of an eco-firm's abatement supply. There are three sets of determinants of an eco-firm's output identified in the first equation of system (1).

$$x_{jit} = x(\underbrace{A_{it}^{T}}_{\substack{\text{abatement}\\ \text{demand}}}, \gamma_{it}, \Psi_{jit}) = x(\underbrace{A_{it}^{L}}_{\substack{\text{local}\\ \text{demand}}}, \underbrace{A_{it}^{O}}_{\substack{\text{outside}\\ \text{demand}}}, \gamma_{it}, \Psi_{jit})$$

The first set is the total market demand (A_{it}^{T}) an eco-firm faces with, including local abatement demand and demand outside the city it locates. The local demand can split into industrial demand and public consumption. Due to the limited environmental articulation in abatement consumption in the large majority of urban and rural areas, public consumption is hardly an important factor in the market demand for abatement goods and services (Liu, 2006; Martens, 2006). The local abatement demand mainly depends on industrial need for pollution abatement. In addition, there is relative clear market demand for industrial abatement, while that for public consumption of abatement is relatively vague and difficult to identify and estimate. Therefore, the local demand for abatement is mainly represented by industrial need for abatement. It is generally expected that a firm's supply of a certain good is positively related to its market demand, thus we would expect a rise in market demand for abatement to increase an eco-firm's output (x_A>0). As for demand outside the city (A_{it}^{T}), transportation cost (trancost) is assumed to be a main factor that affects the abatement demand from other cities. Given other things unchanged, lower transportation cost may increase a firm's competition in market, hence $x_{trancost}$<0.

The second set is environmental regulation stringency. As indicated by David et al. (2011), a stricter environmental policy induces a rotation of inversed abatement demand function which signals to the eco-firms that the polluters become less sensitive to price of abatement goods and services. This motivates eco-firms to raise their price and lower output via the oligopolistic firms' exercise of market power. In our dataset, the abatement output is measured by its value at annual current prices. In order to excluding the inflationary influences and price changes, we deflate output value of each eco-firm with time-invariant and regional different Ex-factory Price Indices of Industrial Products with respect to the industrial sector the eco-firm is in. The base year of Ex-factory Price Indices of Industrial Products is 2000; hence the output value of each eco-firm is adjusted to its value at 2000 constant price. According to David et al. (2011), a stricter environmental policy amplifies the market power effect and induces an eco-firm to produce less. We need to test its coefficient by our estimation.

The third set of determinants is the firm's own characteristics (Ψ_{jit}), which include size, R&D expenses, advertisement expenses, export volume, and ownership status, etc. The impacts of plant characteristics on pollution abatement are an empirical issue.

4.3.2 Industrial abatement volume

Follow Greaker and Rosendahl (2008), we define the environmental regulation standard in city i by γ_i, such that $\gamma_i=1-\frac{E_i-A_i}{Y_i}$, i.e. a higher γ_i implies a more stringent regulation. We have $1-\gamma_i=\frac{E_i-A_i}{Y_i}$, which can be inverted to yield $A_{it}=a(Y_{it},E_{it},\gamma_{it})$. Thus, the necessary amount of abatement effort to reach the city-specific target is then given by $A_{it}=a(Y_{it},E_{it},\gamma_{it})$, implying that the local industrial abatement volume is determined by local economic growth, the scale of industrial emission and regulatory environment. E_{it} here is initial emission generated in industrial production process. It determines the emission volume that requires to be abated ($A_{it}\leq E_{it}$).

As indicated by Panayotou (1997), economic growth (Y_{it}) creates the conditions for social abatement by raising the demand for improved environmental quality and makes the resources available for supplying it. Hence, we expect that the higher the economic growth, the greater demand for abatement.

Besides Y_{it}, E_{it} and γ_{it}, we also introduce industrial human capital level and R&D capacities into the abatement equation. As Lan and Munro (2013) indicated, environmental compliance of industrial polluters is significantly driven by human capital level. An industrial polluter with high human capital level is more likely to install abatement equipment or purchase abatement services. Turning to R&D capacities, abatement technologies and its transformation into industrial application are greatly determined by technological and scientific expenses of local government.

$$A_{it}=a(Y_{it},E_{it},\gamma_{it}, HCI_{it}, TECH_{it})$$

Therefore, on the basis of the above analysis, the abatement demand is now in turn a function of scale effect (Y_{it}), industrial emission volume (E_{it}), regulatory stringency (γ_{it}), industrial human capital intensity (HCI_{it}) and technological expenses by local government ($TECH_{it}$).

4.3.3 Industrial emissions

Follow Grossman and Kruger (1991), we analyze the dynamic evolution of pollutant emissions by distinguishing among three factors: changes in economic activity (scale effect), structural economic changes (composition effect) and changes in sectoral environmental performance (technique effect).

$$E=Y_i \sum_q \frac{Y_{qi}}{Y_i} \frac{E_{qi}}{Y_{qi}}$$

(q: indicator for different sectors, i:indictor for different city, t: indicator for different year)

$$E = e(Y_{it}, \underbrace{\frac{Y_{qit}}{Y_{it}}}_{\substack{\text{composition}\\ \text{effect}}}, \underbrace{\frac{E_{qit}}{Y_{qit}}}_{\substack{\text{technique}\\ \text{effect}}}) = e(Y_{it}, \Omega_{it}, \gamma_{it})$$

Other things kept unchanged, an economy with larger production scale emit more pollution, so we expect a positive coefficient for this term. $\frac{Y_{qit}}{Y_{it}}$ represents the ratio of the value added of sector q in total GDP denoted as composition effect which is frequently used capital abundance measured by capital-labor ratio (k/l) as in Copeland and Taylor (1994), Antweiler et al. (2001), Cole and Elliot (2003) and Cole (2004). We expect a city to have relatively less polluting industrial composition when its industrial production mobilizes relatively more labor forces. The original technique effect ($\frac{E_{qi}}{Y_{qi}}$) is the average pollution intensity. As higher technique effort leads to pollution intensity reduce; most of previous studies frequently used environmental regulation stringency as an approximation for this effect. Hence, technique effect is captured by γ. Given the other two determinants unchanged; we expect tighter environmental policy can reduce emission.

4.3.4 Economic growth

We define economic scale as a Feder (1983) style production function which considers environmental quality as a production factor by supposing industrial emissions as environmental service consumed by production activities. In this function, we suppose real output (Y) is a positive function of the stock of conventional factors of production, labor (L) and capital (K), and the ability to generate industrial emissions after abatement which is the actual pollution level emitted to the environment. Similar to many growth theories, we expect $Y_L>0$, $Y_K>0$, $Y_E>0$. In general, increased investment in abatement activity reduces productive investment and hampers economic growth (Barbera and McConnell, 1990; Gray and Shadbegian, 2004). But the presence of innovations in pollution abatement technology may reconcile (regulated) economic growth with the protection of the ecosystem (Andreoni and Levinson, 2001; Yang et al.,2012). Hence we are uncertain about the sign of Y_A.

4.3.5 Environmental regulation stringency

As discussed by Boyer and Laffont (1999), and the essays collected in Stavins (2004), the design of environmental policy is subject to pressures from public opinion and industrial lobbies. Firstly, if the emission is adjusted one annually, the determination should include the emission level of last year. Second, we postulate that the regulatory stringency is also likely to be determined by its economic growth (Y). There is likely to be a positive linkage between a region's economic growth and the stringency of its regulations (Dasgupta et al., 1995). He (2006) indicates that people become more sensitive to pollution as they get richer; this in turn will result in the intensification of environmental regulation strictness. Thus, we expect that $\gamma_Y>0$. Following the reasoning of Cole et al. (2008) and Lan et al. (2012), everything else equal, we expect a region with a high unemployment rate will tend to have lax environmental regulation and we regard a negative coefficient before unemployment rate (UNemp). Given the same income and population level, higher population density intensifies the marginal damage of pollution. We also include population density as a determinant for environmental regulation stringency and anticipate $\gamma_{popden}>0$. Furthermore, we expect $\gamma_h>0$ as suggested by Lan and Munro (2013), a region with greater proportion of highly educated population might has stricter environmental regulation since highly educated people are more sensitive to environmental quality and more efficient in making complaint to force regulators tighten environmental policy.

4.4. Empirical specification and data choice

4.4.1 Empirical implementation

Follow the method applied by He (2006), we make total differentiation to all five estimation functions and divide each of them by its corresponding dependent variable to facilitate the measurement of the overall regulation effect on industrial abatement demand and individual abatement output. Then we get the following new system as shown below,

$$\frac{dx}{x}=\frac{\partial x}{\partial A}\frac{A}{x}\frac{dA}{A}+\frac{\partial x}{\partial \gamma}\frac{\gamma}{x}\frac{d\gamma}{\gamma}+\frac{\partial x}{\partial trancost}\frac{trancost}{x}\frac{dtrancost}{trancost}+\frac{\partial x}{\partial \Psi}\frac{\Psi}{x}\frac{dx}{d\Psi}$$

$$\frac{dA}{A}=\frac{\partial A}{\partial E}\frac{E}{A}\frac{dE}{E}+\frac{\partial A}{\partial \gamma}\frac{\gamma}{A}\frac{d\gamma}{\gamma}+\frac{\partial A}{\partial Y}\frac{Y}{A}\frac{dY}{Y}+\frac{\partial A}{\partial HCI}\frac{HCI}{A}\frac{dHCI}{HCI}+\frac{\partial A}{\partial TECH}\frac{TECH}{A}\frac{dTECH}{TECH} \quad (2)$$

$$\frac{dE}{E}=\frac{\partial E}{\partial Y}\frac{Y}{E}\frac{dY}{Y}+\frac{\partial E}{\partial \gamma}\frac{\gamma}{E}\frac{d\gamma}{\gamma}+\frac{\partial E}{\partial \Omega}\frac{\Omega}{E}\frac{d\Omega}{\Omega}$$

$$\frac{dY}{Y}=\frac{\partial Y}{\partial A}\frac{A}{Y}\frac{dA}{A}+\frac{\partial Y}{\partial K}\frac{K}{Y}\frac{dK}{K}+\frac{\partial Y}{\partial L}\frac{L}{Y}\frac{dL}{L}+\frac{\partial Y}{\partial E}\frac{E}{Y}\frac{dE}{E}$$

$$\frac{d\gamma}{\gamma}=\frac{\partial \gamma}{\partial E^{net}_{t-1}}\frac{E^{net}_{t-1}}{\gamma}\frac{d\gamma}{\gamma}+\frac{\partial \gamma}{\partial Y}\frac{Y}{\gamma}\frac{dY}{Y}+\frac{\partial \gamma}{\partial Hedu}\frac{Hedu}{\gamma}\frac{dHedu}{Hedu}+\frac{\partial \gamma}{\partial POPden}\frac{POPden}{\gamma}\frac{dPOPden}{POPden}+\frac{\partial \gamma}{\partial Unemp}\frac{Unemp}{\gamma}\frac{dUnemp}{Unemp}$$

This mathematical adjustment transforms each variable in system (1) into its growth rate. Then we estimate the full structure model based on system (2) and specify each equation with all variables in logarithms form as shown in system (3). In system (3), we identify four endogenous variables in this system: $\ln A_{it}$, $\ln E_{it}$, $\ln Y_{it}$ and $\ln\gamma_{it}$. The eight city-level exogenous variables are lnHCI, lnTECH, lnΩ, lnK, lnL, lnHedu, lnPOPden and lnUnemp and one predetermined variable is $\ln E_{t-1}^{net}$, the firm-level variables are assumed to be exogenous since they are not correlated with city level characteristics. The system is overidentified in terms of order condition and rank condition.

$$\ln x_{jit}=a_x^A \ln A_{it}+a_x^g \ln g_{it}+a_x^{transcost}\ln trancost_{it}+a_x^Y \ln Y_{jit}+u_{jit}^x$$

$$\ln A_{it}=a_A^E \ln E_{it}+a_A^g \ln g_t+a_A^Y \ln Y_{it}+a_A^{HCI}\ln HCI_{it}+a_A^{TECH}\ln TECH_{it}+u_{it}^A$$

$$\ln E_{it}=a_E^Y \ln Y_{it}+a_E^g \ln g_{it}+a_E^g \ln W_{it}+u_{it}^E \quad (3)$$

$$\ln Y_{it}=a_Y^A \ln A_{it}+a_Y^K \ln K_{it}+a_Y^L \ln L_{it}+a_Y^E \ln E_{it}+u_t^Y$$

$$\ln g_{it}=a_g^{E^{net}}\ln E_{it-1}^{net}+a_g^Y \ln Y_{it}+a_g^{Hedu}\ln Hedu_{it}+a_g^{density}\ln POPden_{it}+a_g^{UNemp}\ln UNemp_{it}+u_t^g$$

The coefficients represent the elasticities of dependent variables with respect to their independent variables. The indirect impact of regulation stringency on industrial abatement volume can be simply calculated by multiplying the elasticity of industrial abatement volume with respect to the economic determinant by the elasticity of this determinant with respect to regulation stringency. Hence, the total effect of regulation stringency on industrial abatement can be calculated as Eq. (4).

$$\frac{}{\gamma} \quad \alpha^{\gamma} \quad \overbrace{\alpha\ \alpha^{\gamma} \quad \alpha \quad \underbrace{\alpha\ \alpha^{\gamma}}_{}} \tag{4}$$

According to Eq.(4), the total effect of environmental policy stringency on industrial abatement volume decomposes into a direct and an indirect effect. The latter captures the effects through two channels, one is the impact of regulation stringency on emission and resultant impact of emission on industrial abatement; the other one is the impact of regulation stringency on emission and resultant impact of emission-induced economic growth on industrial abatement volume.

Similarly, we calculate the overall effect of regulation stringency on individual abatement output of eco-firms. The effect of regulation stringency on an eco-firm's output can be decomposed into the market power effect and regulation induced demand effect. The indirect effect reflects the impact of regulation stringency on industrial abatement volume and resultant impact of industrial abatement volume on individual abatement output of eco-firms as shown in Eq.(5).

$$\frac{}{\gamma} \quad \alpha^{\gamma} \quad \alpha \quad \underbrace{\underbrace{\alpha^{\gamma} - \alpha\ \alpha^{\gamma} - \alpha\ \alpha\ \alpha^{\gamma}}_{}} \tag{5}$$

The data used in this study is a kind of panel dataset and so we introduce fixed-effects models to control for possible industry and time effects inside each firm and each city. Another benefit of applying fixed effects models is that a SEM application with fixed effect allows controlling for unobserved heterogeneity while dealing with simultaneity. Since we need account for both firm- and city-level fixed effect, we separately estimate each equation in the SEM (3). Besides the time-invariable specific effect which can be controlled by fixed effect estimator, there may exist potential correlation between the residuals of different functions due to the inter-correlation between endogenous variables, which means $cov(\varepsilon_i,\varepsilon_j)\neq0$, where i and j indicate different equation in the system. To get efficient estimates, we use the two-step GMM-IV estimation to control the covariance matrix of the residuals of the system as a whole where the endogenous variables are instrumented by all the exogenous variables [14]. Specifically, we estimate the first specification by controlling firm-level fixed effect and estimate the following four specifications based on city-level fixed effect. In terms of the order condition and the rank condition, each equation in the system is overidentified.

4.4.2 Data and estimation

4.4.2.1 Data sources

To examine the regulatory effects on individual output of eco-firms and industrial abatement in China, this study selects the eco-firms from the Chinese industrial enterprises database (CIED) which embodies information of Chinese industrial enterprises above designated size in China annually from 1996 to 2009. CIED are sample surveys, but they are representative, the total production quantity of surveyed industrial enterprises accounts for 95% of Chinese industrial production quantity. The firm-level data were compiled for 6 eco-industrial sectors for 5 years from 2003 to 2007, for a sample of 3395 observations. Owning to the use of one-lagged variables, the number of observations decreased to 2712. We adopt a traditional definition of eco-industrial sectors, including those sectors that provide products and services aiming at clean-up actions and remedial measures. At the 4-digit level, there are six eco-industries. They are environment protection related industries of medical materials for environmental pollution treatment (2666); environmental pollution prevention equipment (3691); environmental supervision instruments and meters (4121); metal scraps and dross recycling and processing (4310); nonmetal scraps and oddment recycling and processing (4320); sewage water processing and recycling (4620).

The dataset we utilized covers the period from 2003 to 2007. The reason for choosing this period is twofold. First, though the surveys of industrial enterprises are conducted annually, the surveyed indicators are not consistent and appear to be missing in some years. The period we choose includes all the indicators required for this study. Secondly, the use of the selected period is also motivated by the desire to analyze recent trends of stringent environmental regulations promulgated by the State Council in 2003. According to the document of Administration on the

[14] The efficient GMM estimator minimizes the GMM criterion function J=N*g'*W*g, where N is the sample size, g are the orthogonality or moment conditions (specifying that all the exogenous variables, or instruments, in the equation are uncorrelated with the error term) and W is a weighting matrix. In two-step efficient GMM, the efficient or optimal weighting matrix is the inverse of an estimate of the covariance matrix of orthogonality conditions. The efficiency gains of this estimator derive from the use of the optimal weighting matrix, the overidentifying restrictions of the model, and the relaxation of the i.i.d. assumption. For further details, see Hayashi (2000), pp. 206-213 and 226-227 (on GMM estimation).

collection and use of pollution discharge fees, the environmental regulation is tightening annually, which provide more variation in levy charges of pollutants. Table 4.1 and table 4.2 summarize the definitions and summary statistics of all variables. Besides CIED, most of the city-level variables are obtained from Environment yearbook and Statistical yearbooks of key cities. The data for environmental regulation stringency is taken from National Development and Reform Commission for the years 2003-2007. Owing to the limitation of data, the industrial average wage is computed by using firm level wage from CIED for the selected cities. All nominal values are deflated into real value by the implicit price deflator of 1990.

Table 4. 1 Statistical description of the data

Variable	Observations	Unit	Mean	S.D.	Min	Max
		Firm-level variables				
x	3390	1000 Yuan	739.077	2152.051	41.870	69017.170
EXPORT	3390	1000 Yuan	2.867	16.381	0.000	374.93
RD	3390	1000 Yuan	0.231	1.264	0.000	32.57
SIZE	3390	number of employees	135.948	204.508	11.000	2396.00
ADS	3390	Yuan	462.254	324.300	0.000	806021.000
FOREIGN	3390	fraction	0.134	0.341	0.000	1.000
HMT	3390	fraction	0.060	0.246	0.000	1.000
STATE	3390	fraction	0.065	0.238	0.000	1.000
COLLECTIVE	3390	fraction	0.055	0.228	0.000	1.000
PRIVATE	3390	fraction	0.412	0.492	0.000	1.000
		City-level variables				
γ						
SO_2	395	Yuan/KG	0.531	0.171	0.200	1.200
Wastewater	395	Yuan/Ton	0.921	0.353	0.200	1.970
E						
SO_2	395	ton	293.870	213.434	0.140	1313.800
Wastewater	395	ton	23546.700	13768.873	464.000	91260.000
A						
SO_2	395	ton	133.920	98.844	0.000	630.640
Wastewater	395	ton	22496.120	17951.950	444.000	88072.000
transcost	395	million tons	200.262	198.010	3.160	781.080
CAPstock	395	billion yuan	320.890	343.180	12.150	1660.000
INDemp	395	thousand	63.220	56.54	2.110	232.820
HCI	395	1000 Yuan	21.310	7.688	10.706	51.710
Hedu	395	percent	0.068	0.048	0.008	0.301
TECH	395	million Yuan	72.340	361.10	0.790	9074.230
POPdensity	395	per km^2	430.770	314.240	120.860	2661.530
Unemp	395	‰	0.056	0.027	0.001	0.180

Table 4. 2 Data information

Variable	Definitions	Source
	Firm level variables	
x	Annual output value of the eco-firm adjusted by annual constant 2003-2007 prices (NT 10,000Yuan).	China industrial enterprises database
EXPORT	Annual export delivery value of eco-firm adjusted by annual constant 2003-2007 prices	China industrial enterprises database
RD	Annual R&D expenditure of the eco-firm adjusted by annual constant 2003-2007 prices (NT 10,000 yuan)	China industrial enterprises database
SIZE	Annual number of staff and workers	China industrial enterprises database
ADS	Annual advertising expenditure of the eco-firm adjusted by annual constant 2003-2007 prices (10,000Yuan)	China industrial enterprises database
FOREIGN	fraction of paid-in capital contributed by foreign investors	China industrial enterprises database
HMT	Fraction of paid-in capital contributed by Hongkong, Macao and Taiwan investors	China industrial enterprises database
STATE	Fraction of paid-in capital contributed by the state-owned investors	China industrial enterprises database
COLLECTIVE	Fraction of paid-in capital contributed by the collective-owned investors	China industrial enterprises database
PRIVATE	Fraction of paid-in capital contributed by private investors	China industrial enterprises database
	City level variables	
γ	Stringency of environmental regulations measured by annual average treatment charges for industrial wastewater and annual levy for industrial SO_2 emissions	National Development and Reform Commission
A	Industrial wastewater treatment volume and industrial SO_2 abatement volume[15].	Statistical yearbooks of key cities (2004-2008) and Environment yearbook of key cities (2003-2008)
E	Annual total industrial emissions in terms of industrial wastewater emissions and industrial SO_2 emission (NT 10,000tons for wastewater, NT ton for SO_2)	Statistical yearbooks of key cities (2004-2008) and Environment yearbook of key cities (2003-2008)
E^{net}	The value of E-A, annual emission emitted after abatement in terms of industrial SO_2 and industrial wastewater	Statistical yearbooks of key cities (2004-2008) and Environment yearbook of key cities (2004-2008)
transcost	Annual total volume of freight (10,000 tons)	Statistical yearbooks of key cities (2004-2008)
CAPstock	Annual Industrial fixed asset stock 10^9 Yuan, adjusted by1990 price of key cities	Statistical yearbooks of key cities (2004-2008)
INDemp	Staffs and workers employed in industrial sector	Statistical yearbooks of key cities (2004-2008)
HCI	industrial average wage paid to staff (human capital intensity)	Statistical yearbooks of key cities (2004-2008)
Hedu	Ratio of college educated and above population	Statistical yearbooks of key cities (2004-2008)
TECH	Annual scientific and technological expenditure by local government and enterprises.	Statistical yearbooks of key cities (2004-2008)
POPdensity	Population density per km^2	Statistical yearbooks of key cities (2004-2008)
Unemp	Annual unemployment rate ‰	Statistical yearbooks of key cities (2004-2008)

[15] The industrial abatement includes both end-of-pipe abatement and cleaner production abatement.

4.4.2.2 Data choice for environmental regulation stringency

According to Kesidou and Demirel (2012), the stringency of environmental regulations is often proxied with abatement costs. In the presence of differences in regulatory stringency with respect to different kinds of pollutants, we choose charges for SO_2 emission and treatment charges for industrial waste water as two proxies for local environmental regulation stringency.

4.4.2.2.1 Proxy for environmental regulation stringency of SO_2 emissions

With one-third of China's territory widely reported to be affected by acid rain, the formation of which SO_2, contributes to, reducing SO_2 emissions has been the key environmental target in China. By amending the 1987 Atmospheric Pollution Prevention and Control Act in August 1995, which newly added SO_2 emission from coal combustion as the regulated pollutant, China has since 1996 started levying the charges for SO_2 emissions in the so-called Two Control Zones based on the total quantity of emissions and at the rate of Yuan 0.20 per kilo of pollution equivalent (Yu, 2006). As indicated in Table 4.3, since July 2003, this charge was applied nationwide and the charge rate was raised step by step. From 1 July 2005 onwards, the charge was applied at the level of Yuan 0.60 per kilo of pollution equivalent [16]. To help meet the energy-saving and environmental control goals set for the 11th five-year economic plan, the Chinese government plans to double the charges for SO_2 emissions in three steps from the existing level to Yuan 1.2 per kilo of pollutant equivalent within the next three years (The State Council, 2007). Local governments are allowed to raise pollution charges above the national levels, and thus levies vary with the weight placed upon environmental protection by local authorities (Dasugpta, et al., 2001). The SO_2 charges are collected by local environmental protection bureaus and offices in the area where the polluting enterprises are located and the original pollution levy rules also stipulate 80% of environmental revenue to be used to fund pollution prevention measures (Cao et al., 1999). Considering this situation, the levy rate with respect to SO_2 emissions in Chinese cities represent, to some extent, the abatement efforts through policy-flavored intervention by local governments. Therefore, we prefer to use the actual local levy rate with respect to SO_2 emissions to measure the actual local regulatory stringency faced by an industrial polluter.

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[16] Since 1999, Beijing charges 1.2 Yuan per kilo of pollution equivalent for SO2 emissions; Hangzhou and Jilin raised charges for SO_2 emissions from 0.2 Yuan to 0.6 Yuan per kilo of pollution equivalent from 1 July 2003; Zhengzhou charges 0.5 Yuan per kilo pollution equivalent for SO_2 emission from 1 July 2003 to July 2004 and the rate raised to 0.6 Yuan per kilo pollution equivalent at 1 July 2005 (SEPA et al., 2003). Jiangsu province raised charges for SO_2 emissions from the existing level of Yuan 0.6 to Yuan 1.2 per kilo of pollution equivalent from 1 July 2007 onwards, three years ahead of the National schedule (Zhang, 2011).

4.4.2.2.2 A proxy for environmental regulation stringency of industrial wastewater

To measure China's regulatory stringency of industrial waste water, we use an effective charge for industrial waste water treatment. As Smarzynska and Wei (2001) emphasize, many studies have had to rely on very broad proxies for environmental stringency, potentially causing measurement error. The availability of local treatment charges for industrial wastewater allows us to specify the stringency of regulations using a price-based policy instrument at the level of administration. In this study, we choose treatment charge for industrial wastewater which is frequently used as a proxy for environmental regulation stringency (Dasgupta et al. 2001; Wang, 2002; Wang and Wheeler, 2003; Dean et al., 2009) based on the following considerations. First, it reflects actual charges to firm's per unit of polluted wastewater [17]. In most cities, the charge standard of wastewater treatment is set lower than its cost. From the economic point of view, facing low pollution treatment charge, polluters may prefer sending their wastewater emission to sewage treatment factories and paying a treatment charge to taking more costly measures to abate their emissions. So the wastewater treatment charge indirectly reflects the difference in enforcement capacity of environmental regulation at the local level. Besides, the local treatment charge of wastewater is set and collected by the local environmental protection bureaus and offices. The majority of charge revenue is used to develop local environmental institutions and to finance public-sector environmental projects, which strongly motivates environmental authorities to enforce the system of wastewater treatment charges (Wang and Wheeler, 2003). The standard of wastewater treatment charge varies across cities and over time. According to Dean et al.(2009), part of the variation is due to differences in pollutant concentration standards, which are determined jointly by the national and the local governments. Therefore, we can conclude that the variation in local treatment charges is not primarily driven by actual treatment costs.

4.5. Results

4.5.1 Structural equations

Table 4.4 displays the results obtained using two-step GMM estimator of panel data models with fixed-effects to estimate each equation in SEM (3). We can see that the overall fit of system is good. The fixed effects specification is found to be strongly favored by hausman test in all models. In most cases, the instrumental variables strongly correlate with the instrumented

[17] The average charge for urban sewage treatment was reported to be Yuan 0.7 per ton for 36 large and medium cities in China by the end of 2008, whereas the corresponding treatment cost is Yuan 1.1 per ton (NDRC, 2009; CAEP, 2009).

endogenous variables and the model passes the underidentification tests. The Kleibergen-Paap rk LM statistics of underidentification tests suggest that we can reject the null hypothesis of underidentification, which means that the estimated equations are identified in that the instruments are correlated with the endogenous regressors. In most scenarios, the Cragg-Donald Wald F statistics compare favorably to the statistics reported in Stock and Yogo (2005), which suggest that we can comfortably reject the null hypothesis of weak instruments. The Sargan tests of overidentifying restrictions fail to reject the null hypothesis that the instruments are uncorrelated with the error term and that the specifications are correct.

4.5.1.1 Determinants of abatement output

The abatement output equation as shown in column (1) and column (6) in Table 4.4 explains the determinants that influence the individual output of eco-firms. The coefficients on abatement demand (lnA) are in the expected direction for SO_2 and wastewater, implying the positive demand effect. As for regulatory stringency of controlling industrial SO_2 emission, it is found to be negatively associated with individual abatement output, confirming the expectation that market power effect induce eco-firms to produce less. However, the significance of $\ln\gamma$ is weak for both cases. This implies that eco-firms are not sensitive to the stringency of environmental regulation, reflecting the fact that current standards of pollution charges are set to low to induce eco-firms to react by adjusting outputs. As for the influences of other control variables, the coefficients are also measured with good precision and demonstrate strong and plausible effects. Turing to our firm-level variables, model (1) and model (6) in Table 4.4 show that abatement supply of an eco-firm is a positive and significant function of EXPORT suggesting that exports-oriented firms tend to have more abatement supply, other things being equal. Not surprisingly, abatement output function is a positive function of research and development expenditure, RD, suggesting that innovation within firms contribute a firm's abatement supply. As for the ownership composition[18], paid-in capital contributed by state-owned investors (STATE) is shown to have significantly negative impact on abatement supply by eco-firms. We cannot find significant coefficients for other ownership variables. Besides, the coefficient for transportation cost (transcost) is not statistically significant. This indicates that there is no significant evidence that abatement

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[18] The State Statistical Bureau of China (SSB) assigns to each firm in the database a categorical variable indicating ownership status. Nevertheless, it is also possible to construct a continuous measure of ownership composition from the database by looking at the fraction of paid-in capital contributed by the state and private and foreign investors. This feature is useful when it comes to distinguishing between SOEs that are liquidated and those that are transferred to non-state hands.

suppliers can benefit more through lower transportation cost brought about by economies of scale of large freight volume.

4.5.1.2 Determinants of industrial abatement volume

Model (2) and model (7) in Table 4.4 provides our estimates of industrial abatement volume with respect to industrial SO_2 and industrial wastewater. Local economic growth (lnY) is found to be significantly positive related to abatement volume of industrial wastewater emissions but it is estimated to be significantly negative associated with abatement volume of industrial SO_2 emissions. The positive coefficients before E_{it} confirm the fact that the abatement decision of industrial polluters might be based on actual emission scale of industrial sectors. Regulatory stringency (Lnγ) is found to be positive, significant determinant of abatement demand of both. The variable lnTECH is estimated to be a positive but insignificant determinant of abatement volume of both pollutants. Finally, the variable lnHCI is estimated to be a positive, significant determinant of industrial SO_2 abatement, but an insignificant determinant of industrial wastewater, reflecting that human capital's impact on pollution abatement differs with respect to different pollutants. Human capital level has a significant effect on installment and absorption of advanced desulfurization technology, whilst its impact is insignificant on wastewater treatment technologies which have been widely applied in industrial production.

4.5.1.3 Determinants of industrial emission

Model (3) and model (8) of Table 4.4 give the estimation results for industrial SO_2 emissions and wastewater emission respectively. Confirming theoretical anticipation of Grossman decomposition, estimation produces the positive and significant coefficients of scale effect and composition effect for both pollutants. The significantly negative coefficients of regulatory stringency variable (lnγ) for both industrial SO_2 emissions and industrial wastewater emissions reveal the fact that both the levy charges of industrial SO_2 or treatment charges of industrial wastewater have a deterrent effect on the increase of industrial emissions.

4.5.1.4 Determinants of economic growth

Model (4) and model (9) display estimate results obtained using economic growth as the dependent variable. First, two factors of production, capital stock (lnCAPstock) and labor (lnINDemp) are positively related to GDP in both model (3) and model (8). Interestingly, abatement demand (lnA) of industrial wastewater is estimated to be a positively correlated with economic growth; while the abatement demand of SO_2 emissions is found to be negatively related to economic growth. The intuitive explanation is that Chinese industrial polluters might take different attitudes towards pollution abatement of wastewater and SO_2 in response to a stricter environmental regulation. In fact, this result can be attributed to the widespread adoption of industrial wastewater abatement technology and an increasing number of urban sewage treatment centers in most Chinese cities. It is relatively easier to master the wastewater abatement technology and rearrange the combination of production inputs, hence industrial GDP growth can be obtained from a careful redesign of the production process induced by the need to comply with environmental regulations. The SO_2 abatement technology, unlike the wastewater treatment technology, is not widely used. In particular, the industrial application of desulfurization technology is still at the experimental stage. When a firm allocates resources to abatement activities, this is conventionally believed to reduce productivity measured by ordinary outputs (Telle and Larsson, 2007). An increase in SO_2 abatement expenditures would raise production cost and result in a negative impact on economic growth. Finally, total emissions of both pollutants generated in industrial production (lnE) are found to be the significant determinants of economic growth.

4.5.1.5 Determinants of environmental regulation stringency

In contrast to He's (2006) finding that the policy decision on pollution control effort of industrial SO_2 emissions is not based on the actual situation, both industrial SO_2 emission and industrial wastewater emissions of last year (lnE_{t-1}) are found to possess a positive, statistically significant, relationship with the strictness of environmental regulation in both model (5) and (10). This difference in the conclusions may be attributed to different measurements for environmental stringency. Economic growth (lnY) is found to be positively related to strictness of environmental regulations on both SO_2 and wastewater, which is consistent with previous findings in Wang and Wheeler (1996) and He (2006), supporting the view that economic growth facilitates an increase in public demand for a better environment which will result in the intensification of environmental regulation stringency. As expected, we find a positive correlation between human capital level of city and stringency of environmental regulation, at least in terms of regulatory stringency of controlling industrial SO_2 emissions. Finally, unemployment rate (UNEMP) is estimated to be a negative, significant determinant of regulatory stringency on both pollutants, whilst population density (POPdensity) is found to be an insignificant determinant of both SO_2 regulation stringency and industrial wastewater regulation stringency. The significantly negative correlation between regulation stringency and the unemployment rate confirms Gray and Deily's

(1996) and Cole et al.'s (2008) findings that high level of unemployment limits the scope for active environmental policies.

Table 4. 3 The simultaneous system estimation results (2-Step GMM estimation for simultaneous system, fixed effect, main Chinese industrial cities during the period 2003-2007)

Variables	Regulatory stringency of SO_2					Regulatory stringency of wastewater				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	lnx	lnA	lnE	lnY	lnγ	lnx	lnA	lnE	lnY	lnγ
lnA	0.241***			-0.017*		0.517***			0.332*	
	(0.056)			(0.011)		(0.031)			(0.189)	
lnY		-0.235*	0.066***		0.209***		0.360***	0.274***		0.393*
		(0.127)	(0.018)		(0.038)		(0.115)	(0.076)		(0.223)
lnΩ			0.094**					0.136*		
			(0.045)					(0.077)		
lnγ	-0.016	0.238***	-0.168***			0.087	0.456***	-0.392***		
	(0.033)	(0.074)	(0.055)			(0.112)	(0.135)	(0.130)		
lnE		0.746***		0.048***			0.886***		0.134**	
		(0.278)		(0.023)			(0.221)		(0.067)	
lagged $\ln E^{net}$					0.155**					0.031**
					(0.067)					(0.014)
lnEXPORT	0.092***					0.115***				
	(0.027)					(0.026)				
lnRD	0.250**					0.237				
	(0.120)					(0.630)				
lnSIZE	0.213***					0.109***				
	(0.292)					(0.021)				
lnADS	0.308**					0.357*				
	(1.536)					(0.187)				
lnFOREIGN	-0.032					-0.102				
	(0.074)					(0.083)				
lnHMT	0.089					0.102				
	(0.062)					(0.085)				
lnSTATE	-0.157**					-0.148**				
	(0.072)					(0.070)				
lnCOLLECTIVE	-0.077					-0.107				
	(0.052)					(0.068)				
lnPRIVATE	0.042					0.025				
	(0.037)					(0.038)				
lntranscost	0.135					-0.119				
	(0.887)					(0.087)				
lnCAPstock				0.292***					0.751***	
				(0.319)					(0.238)	
lnINDemp				0.052**					0.098	
				(0.019)					(0.179)	
lnTECH		0.016					0.054			
		(0.011)					(0.043)			
lnHCI		0.004**					0.016			
		(0.002)					(0.012)			
lnHedu					0.016**					0.023
					(0.008)					(0.027)

a. ***, ** and * denote significance at 99%, 95% and 90%, respectively

b. Model (1) and (6) use firm fixed effects, and the reported standard errors are robust to heteroskedasticity and adjusted for clusters by cities. Other models use city fixed effect, and the reported standard errors are robust to heteroskedasticity.

c. The heteroskedasticity is corrected by the White's heteroskedasticity consistent covariance matrix.

d. The J-statistics is obtained from Sargan test of the validity of all instruments.

e. Reduction in the number of observations is due to the data transformation, such as lagged variable and logarithms form.

Table 4.3 (Continued)

Variables	Regulatory stringency of SO_2					Regulatory stringency of wastewater				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	lnx	lnA	lnE	lnY	lnγ	lnx	lnA	lnE	lnY	lnγ
lnPOPdensity					0.025 (0.029)					0.034 (0.014)
lnUnemp					-0.189** (0.108)					-0.373* (0.202)
Hausman (fixed effect)	206.54 (0.000)	54.27 (0.014)	71.28 (0.000)	62.01 (0.008)	42.12 (0.023)	245.74 (0.000)	73.22 (0.000)	86.73 (0.000)	76.98 (0.000)	61.24 (0.004)
Kleibergen-Paap rk LM statistic (Underidentification test)	10.051 {0.092}	7.646 {0.083}	43.573 {0.000}	7.014 {0.092}	172.268 {0.000}	15.859 {0.044}	13.256 {0.033}	10.778 {0.088}	6.127 {0.127}	12.663 {0.013}
Cragg-Donald Wald F statistic (Weak identification test)	30.708	45.34	6.205	16.886	101.307	19.540	11.540	7.336	12.208	106.526
Sargan statistics (system identification)	5.814 {0.325}	2.214 {0.696}	2.325 {0.887}	2.750 {0.431}	1.223 {0.747}	5.928 {0.313}	5.216 {0.266}	8.310 {0.140}	4.151 {0.245}	1.245 {0.742}
Observation	2317	308	308	308	308	2317	308	308	308	308

a. ***, ** and * denote significance at 99%, 95% and 90%, respectively

b. Model (1) and (6) use firm fixed effects, and the reported standard errors are robust to heteroskedasticity and adjusted for clusters by cities. Other models use city fixed effect, and the reported standard errors are robust to heteroskedasticity.

c. The heteroskedasticity is corrected by the White's heteroskedasticity consistent covariance matrix.

d. The J-statistics is obtained from Sargan test of the validity of all instruments.

e. Reduction in the number of observations is due to the data transformation, such as lagged variable and logarithms form.

4.5.2 Effect of regulatory stringency

In Table 4.4 and Table 4.5, we calculate the direct, indirect and total impact of environmental regulation stringency on industrial abatement demand and an eco-firm's output by using the estimated coefficient as shown in Table 4.3. The effects and corresponding standard errors are computed using the delta method.

4.5.2.1 Effect of environmental regulation stringency on industrial abatement demand

From Table 4.4 below, we can see that the regulation stringency of both pollutants has a significant positive direct effect and a significant negative indirect effect on industrial abatement demand. Though the indirect effects are negative, the overall impacts of environmental regulation stringency on industrial abatement demand are estimated to be positive, implying that a strict environmental policy can contribute to the improvement of industrial environmental performance. Our results show that a 1% increase in the levy charge of industrial SO_2 emission increases industrial SO_2 abatement volume by 0.114%; a 1% increase in the treatment charge of industrial wastewater will lead to an increase in industrial abatement volume by 0.091%.

Table 4. 4 The impact of environmental regulation stringency on industrial abatement demand

Regulation stringency of target pollutant	Direct effect α_A^γ	Indirect effect $\alpha_A^E\alpha_E^\gamma+\alpha_A^Y\alpha_Y^E\alpha_E^\gamma$	Total effect $\alpha_A^\gamma+\alpha_A^E\alpha_E^\gamma+\alpha_A^Y\alpha_Y^E\alpha_E^\gamma$
SO_2	0.238***	-0.124**	0.114**
	(0.074)	(0.059)	(0.058)
Wastewater	0.456***	-0.365**	0.091**
	(0.108)	(0.166)	(0.043)

a. The effects and corresponding standard errors are computed by using delta method.
b. ***, ** and * denote significance at 99%, 95% and 90%, respectively.

4.5.2.2 Effect of environmental regulation stringency on individual abatement supply

Turning to the effect of regulation stringency on individual abatement supply as shown in Table 4.5, the regulation induced market power effect on an eco-firm's abatement supply is found to be insignificant. This result implies that regulation-amplified market power effect does not exist in eco-firms of our sample. It may be attributed to the relatively lower treatment charges which somehow make abatement producer yields less sensitive to the stringency of environmental regulation. Hence the overall effect is owing to the regulation-induced demand effect, implying that a 1% increase in the levy charge of industrial SO_2 emission and the treatment charge of industrial wastewater emission will lead to an increase in an eco-firm's output value by 0.025% and 0.049% respectively.

It is notable that the effect of wastewater regulation stringency on individual abatement output is estimated to be greater than that of SO_2 regulation stringency on individual abatement output. In abatement market, the majority of ready-made provided is wastewater related abatement goods and services, which may induce eco-firms to be more sensitive to environmental policy of wastewater emissions.

Table 4. 5 The impact of environmental regulation stringency on individual abatement supply

Regulation stringency of target pollutant	Regulation induced market power effect	Regulation induced demand effect	Total effect
	α_x^γ	$\alpha_x^A(\alpha_A^E\alpha_E^\gamma+\alpha_A^Y\alpha_Y^E\alpha_E^\gamma)$	$\alpha_x^\gamma+\alpha_x^A(\alpha_A^E\alpha_E^\gamma+\alpha_A^Y\alpha_Y^E\alpha_E^\gamma)$
SO_2	-0.016 (0.033)	0.025* (0.014)	0.009 (0.009)
Wastewater emissions	0.087 (0.112)	0.049** (0.023)	0.136 (0.267)

a. The effects and corresponding standard errors are computed by using delta method.
b. ***, ** and * denote significance at 99%, 95% and 90%, respectively.

4.5.3 Regulation effect on individual abatement output of different eco-industrial sectors

In general speaking, a stricter environmental policy does not only contribute to better industrial environmental performance but also increase the average individual abatement output of the whole eco-industry. In the datasets, the eco-industry includes 6 sectors. They are environment protection related industries of medical materials for environmental pollution treatment (2666); environmental pollution prevention equipment (3691); environmental supervision instruments and meters (4121); metal scraps and dross recycling and processing (4310); nonmetal scraps and oddment recycling and processing (4320); sewage water processing and recycling (4620). Since the function of abatement products varies tremendously across different eco-industrial sectors, the output decisions of eco-firms in each sector may be quite different in response to environmental regulation stringency. Hence, to clarify the relationship between environmental regulation and individual abatement output with respect to different eco-industrial sectors, we divide the sample into 5 subsets according to their classified sectors. The results are shown in Table 4.6 and Table 4.7.

From the city-level regression results, we have known that the overall regulation effects on abatement demand of industrial SO_2 emission and industrial wastewater emission are 0.114 and

0.091 respectively. To see the magnitude of regulation effect on individual abatement output of different eco-industrial sectors, we calculate the regulation-induced market power effect, the regulation-induced demand effect and the total effect by using the coefficients obtained from Table 4.6 and Table 4.7.

As shown in Table 4.8, in most scenarios, the regulation-amplified market power effect is invalid. However, we find that a stricter environmental policy for controlling industrial SO_2 and industrial wastewater can induce an eco-firm in environmental supervision instruments and meters sector (4121) to produce less via its market power. This is reflected, for example, in the fact that the eco-firms that produce pollution supervision instruments are more policy-oriented since their products are used to monitor, supervise and measure the volume of emissions. Though we find valid market power effect for eco-firms in environmental supervision instruments and meters sector, the total effect is positive due to the greater regulation-induced demand effect.

Besides we also find a stringent environmental policy for controlling industrial wastewater decreases individual abatement output value of eco-firms in sewage water processing and recycling sector (4620). The absolute value of negative regulation-induced market power effect finally exceeds the positive regulation-induced demand effect, resulting in negative total effect. With the widely adoption of wastewater treatment technology in China, it is relatively easier to operate a sewage treatment factory with technical backup. Besides, China has stipulated relevant policies to encourage private and foreign investment in wastewater treatment facilities. This lowers the threshold for market entry of operating sewage treatment business and so attracts more entrants. The decreasing individual abatement output and the increasing number of urban sewage treatment centers reflect the existence of "business stealing effect" in sewage treatment sector. The business-stealing effect is present when the equilibrium strategic response of existing firms to new entry results in their having a lower volume of supply-that is, when a new entrant "steals business" from incumbent firms (Mankiw and Whinston, 1986; Breshahan andReiss, 1990, 1991).

Table 4. 6 Estimates for individual abatement output of eco-firms of different sectors based on SO_2 regulation stringency (2-step GMM, fixed effect, main Chinese industrial cities during the period 2003-2007)

Variables	Sectors of eco-firms									
	2666		3691		4121		4310/4320		4620	
lnA (industrial SO_2 abatement)	0.714***	(0.337)	0.254**	(0.119)	0.221**	(0.102)	0.195***	(0.769)	0.355***	(0.116)
lnγ (SO_2 regulation)	0.044	(0.126)	-0.013	(0.012)	-0.019*	(0.011)	-0.027	(0.083)	-0.015	(0.037)
lnEXPORT	0.149*	(0.087)	0.115**	(0.054)	0.291	(0.262)	0.177	(0.126)	0.240	(0.213)
lnRD	0.796	(3.974)	0.189*	(0.106)	-0.264	(0.584)	0.527**	(0.229)	0.218	(0.286)
lnSIZE	0.039	(0.071)	0.366***	(0.064)	0.512**	(0.233)	0.138	(0.089)	0.235	(0.174)
lnADS	0.185	(0.197)	0.251***	(0.057)	0.707	(0.614)	-0.845	(1.176)	-0.742	(0.713)
lnFOREIGN	-0.112	(0.739)	0.098	(0.138)	0.008	(0.028)	-0.110	(0.149)	0.551**	(0.263)
lnHMT	-0.248*	(0.139)	0.238	(0.175)	0.084	(0.169)	-0.103	(0.153)	0.224	(0.183)
lnSTATE	-0.108	(0.292)	-0.418**	(0.202)	0.408***	(0.094)	-0.081	(0.431)	-0.078	(0.137)
lnCOLLECTIVE	0.188**	(0.086)	-0.059	(0.085)	0.058***	(0.093)	0.080	(0.139)	-0.033	(0.122)
lnPRIVATE	0.027	(0.107)	0.075	(0.056)	0.094	(0.182)	-0.123	(0.097)	0.068	(0.069)
lntranscost	0.469	(0.376)	0.124	(0.159)	0.401	(0.316)	0.132	(0.141)	0.214*	(0.120)
Kleibergen-Paap rk LM statistic (Underidentification test)	16.563	{0.029}	14.032	{0.063}	9.958	{0.268}	9.902	{0.272}	13.702	{0.086}
Cragg-Donald Wald F statistic (Weak identification test)	32.055		22.035		5.640		11.030		21.993	
Sargan statistics (system identification)	10.083	{0.184}	15.592	{0.029}	6.892	{0.440}	7.675	{0.362}	6.770	{0.453}
Observation	280		1264		144		746		202	

a. ***, ** and * denote significance at 99%, 95% and 90%, respectively.

b. The results are based on firm-level analysis in which the endogenous variables lnA and lnγ are instrumented by all system exogenous variables.

c. The variable A in this case is industrial SO_2 abatement volume and the variable γ is environmental regulation stringency of industrial SO_2 emissions.

d. The reported standard errors are robust to heteroskedasticity and adjusted for clusters by cities.

e. The J-statistics is obtained from Sargan test of the validity of all instruments.

f. Reduction in the number of observations is due to the data transformation, such as lagged variable and logarithms form.

Table 4. 7 Estimates for individual abatement output of eco-firms of different sectors based on industrial wastewater regulation stringency (2-step GMM, fixed effect, main Chinese industrial cities during the period 2003-2007)

Variables	Sectors of eco-firms									
	2666		3691		4121		4310/4320		4620	
lnA (wastewater abatement)	0.859**	(0.437)	0.822***	(0.183)	0.608**	(0.298)	0.208	(0.142)	0.326**	(0.134)
lnγ (wastewater regulation)	0.086	(0.134)	0.128	(0.237)	-0.039*	(0.021)	0.082	(0.091)	-0.106**	(0.049)
lnEXPORT	-0.154**	(0.078)	0.120**	(0.048)	-0.418	(0.337)	0.306***	(0.117)	0.203	(0.236)
lnRD	0.114	(0.182)	0.150	(0.102)	-0.360	(0.479)	0.634***	(0.235)	0.231	(0.286)
lnSIZE	0.002**	(0.001)	0.329***	(0.067)	0.586***	(0.192)	0.099	(0.163)	0.272	(0.166)
lnADS	0.504**	(0.232)	0.267***	(0.052)	0.641	(0.927)	-0.157	(0.169)	-0.734	(0.787)
lnFOREIGN	-0.372	(0.277)	0.163	(0.117)	0.404	(0.333)	-0.082	(0.148)	0.587**	(0.231)
lnHMT	-0.308***	(0.112)	0.317	(0.131)	0.084	(0.169)	-0.103	(0.153)	0.184	(0.242)
lnSTATE	-0.324	(0.359)	-0.375	(0.319)	0.293***	(0.106)	0.192	(0.237)	-0.082	(0.127)
lnCOLLECTIVE	0.188**	(0.086)	-0.096	(0.129)	0.129***	(0.179)	0.112	(0.142)	-0.119	(0.113)
lnPRIVATE	-0.054	(0.081)	0.044	(0.058)	0.061	(0.182)	-0.072	(0.095)	0.069	(0.088)
lntranscost	0.533	(0.342)	0.034	(0.155)	0.401	(0.316)	0.143	(0.173)	0.058	(0.183)
Kleibergen-Paap rk LM statistic (Underidentification test)	16.308	{0.037}	15.181	{0.056}	10.785	{0.214}	15.865	{0.044}	15.914	{0.042}
Cragg-Donald Wald F statistic (Weak identification test)	32.338		17.034		4.411		30.233		34.101	
Sargan statistics (system identification)	5.503	{0.599}	14.002	{0.051}	9.228	{0.237}	10.261	{0.174}	4.294	{0.745}
Observation	280		1264		144		748		204	

a. ***, ** and * denote significance at 99%, 95% and 90%, respectively.

b. The results are based on firm-level analysis in which the endogenous variables lnA and lnγ are instrumented by all system exogenous variables.

c. The variable A in this case is industrial wastewater abatement volume and the variable γ is environmental regulation stringency of industrial wastewater emissions.

d. The reported standard errors are robust to heteroskedasticity and adjusted for clusters by cities.

e. The J-statistics is obtained from Sargan test of the validity of all instruments.

a. Reduction in the number of observations is due to the data transformation, such as lagged variable and logarithms form.

Table 4. 8 Regulation effect on individual abatement output of different eco-industrial sectors

Eco-industrial Sectors	α_x^A	$\alpha_A^E\alpha_E^\gamma+\alpha_A^Y\alpha_Y^E\alpha_E^\gamma$	Regulation effect on individual abatement output: Market power effect α_x^γ	Demand effect $\alpha_x^A(\alpha_A^E\alpha_E^\gamma+\alpha_A^Y\alpha_Y^E\alpha_E^\gamma)$	Total effect $\alpha_x^\gamma+\alpha_x^A(\alpha_A^E\alpha_E^\gamma+\alpha_A^Y\alpha_Y^E\alpha_E^\gamma)$
Regulation stringency of industrial SO_2					
2666	0.714*** (0.337)	0.114** (0.058)	0.044 (0.126)	0.081** (0.039)	0.125 (0.098)
3691	0.254** (0.119)	0.114** (0.058)	-0.013 (0.012)	0.029* (0.016)	0.016 (0.041)
4121	0.221** (0.102)	0.114** (0.058)	**-0.019*** (0.026)	0.025* (0.013)	0.006* (0.004)
4310/4320	0.195*** (0.769)	0.114** (0.058)	-0.027 (0.083)	0.022** (0.011)	-0.005 (0.017)
4620	0.355*** (0.116)	0.114** (0.058)	-0.015 (0.037)	0.040* (0.023)	0.035 (0.043)
Regulation stringency of industrial wastewater					
2666	0.859** (0.436)	0.091** (0.043)	0.086 (0.134)	0.078** (0.038)	0.164 (0.231)
3691	0.822*** (0.183)	0.091** (0.043)	0.128 (0.237)	0.074** (0.035)	0.202 (0.477)
4121	0.608** (0.298)	0.091** (0.043)	-0.039** (0.019)	0.055* (0.028)	0.016* (0.0088)
4310/4320	0.208 (0.142)	0.091** (0.043)	0.082 (0.091)	0.018 (0.020)	0.100 (0.142)
4620	0.326** (0.134)	0.091** (0.043)	**-0.106**** (0.049)	0.029** (0.018)	**-0.077**** (0.037)

a. The effects and corresponding standard errors are computed by using delta method.

b. ***, ** and * denote significance at 99%, 95% and 90%, respectively.

4.6 Concluding remarks and policy implications

Taking into account the facts that regulatory stringency may differ according to its target pollutants; this study investigates the changes of industrial abatement volume as well as individual output of eco-firms in response to stringency of environmental regulation. On the basis of a panel dataset of 678 eco-firms in 78 Chinese industrial cities during the period 2003-2007, we adopt both two-step GMM and 3SLS fixed effect estimation of simultaneous equations to implement the analysis and derive interesting and of note findings.

The results have shown that a more stringent environmental regulation of both industrial SO_2 and industrial wastewater emissions, do not only contribute to the improvement of industrial environmental performance but also extend a helping hand to the development of eco-firms. With respect to the regulatory impact on industrial abatement demand, although the indirect effect of regulation stringency on industrial abatement volume is negative, the overall effect is positive for both pollutants. Turning to the regulatory impact on individual abatement supply, we find that the regulation-amplified market power effect is found to be insignificant; instead, regulation stringency can affect an eco-firm's output through its impact on industrial abatement demand. Furthermore, when investigating the relationship between environmental regulation stringency and individual abatement output of different eco-industrial sectors, the overall effect of industrial wastewater regulation on individual abatement output of sewage treatment sector is found to be negative, implying the existence of business stealing effect in sewage treatment sector.

The findings in this study have important policy implications. In general cases, the regulation induced market power effect triggers the greater individual abatement output values of Chinese eco-firms. The treatment charge of industrial wastewater is in the range of 0.2-1.97, and the levy charge of SO_2 is in the range of 0.2-1.2 in the sample period. Considering the current situation in China, the emission charges are set too low; raising the charges, is suggested to improve industrial environmental performance and facilitate the development of eco-firms. However, regarding the negative regulation effect of industrial wastewater in sewage treatment sector, the results suggest that simply raising the treatment charge of industrial wastewater might result in lower individual output values of eco-firms in sewage treatment sector.

Besides, regarding the relationship between abatement and environmental regulation stringency, the results differ with respect to industrial SO_2 emissions and industrial wastewater emissions. Accordingly, different policy suggestions are required to balance economic growth and industrial abatement of SO_2 and wastewater. With respect to industrial SO_2 emission control, our results show that though stricter environmental regulation can contribute to the development of eco-firms, there exists a tradeoff between SO_2 abatement and economic growth due to relatively high cost of desulfurization technologies as discussed in section 5.1.3 of Chapter 4. A win-win situation between development of eco-industry and economic growth can be reached only if there are well-designed environmental regulations. It suggests the more tightening regulation of industrial SO_2 should be on the condition that innovation of SO_2 abatement technologies is widely applied in industrial production with low cost. Hence, the alternative strategy should provide more appealing incentive to undertake the innovation of SO_2 abatement technologies and accelerate its transformation into industrial application. Turning to regulatory stringency of industrial wastewater, in general cases, we find that regulation-induced abatement of wastewater not only benefits to economic growth but also contributes to the development of eco-firms. As mentioned previously, the treatment charges for industrial wastewater are set too low to stimulate eco-firms' initiatives for providing abatement goods and services and so higher charges are required to achieve the possibility for ecological-economic win-win solution. But from the standpoint of the development of eco-firms, the negative relationship between environmental regulation stringency and individual abatement output of eco-firms in the sewage treatment sector suggests that the number of eco-firms in the sewage treatment sector should be controlled at a certain level to relieve the problem brought about by business stealing effect.

We finish on a note of caution. We see this paper as a first attempt to examine the complex linkage between regulatory stringency and demand for and supply of abatement for a large developing country such as China. In addition, we do not know whether the relationships estimated in this paper apply to pollutants other than SO_2 and wastewater. Unfortunately, these are currently the only two pollutants for which the data of industrial abatement volume are available in China. Inevitably, the study would be benefited from a richer dataset with more pollutants in a longer period. In time, such data may be forthcoming and so allowing more sophisticated analysis.

Although we have examined the effect of environmental regulation stringency on industrial abatement and individual output of eco-firms, we did not take into account the possibility that regulatory effect might differ with respect to different types of abatement goods and services. As indicated by Frondel et al. (2004), industrial polluters might have different abatement selections in response to a more stringent environmental policy set up by the government; they may adopt end-of-pipe technologies or install cleaner production technologies. So environmental stringency might stimulate different market demands for abatement in terms of end-of-pipe technologies and cleaner production technologies, thereby leads to different abatement output. Therefore, it would be interesting to analyze eco-firms' output decision by comparing regulation effects on end-of-pipe abatement and cleaner production abatement.

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CHAPTER 5 CONCLUSION

5.1 Discussions

This section gathers the results from the two analytical studies that form the core of this thesis and offers some broad conclusions.

In the last two decades, there has been a well-developed strand of environmental economics works analyzing the strategic use of environmental policy on pollution control. However, while the academic world has done much to improve our understanding of environmental regulation and pollution control, many questions remain unanswered. For instance, how to push firms to improve their environmental performance when the enforcement of environmental regulation varies tremendously across regions? Regarding the current circumstance, industrial polluters are heavily reliant upon abatement products and services delivered by eco-firms. Then what the consequence for eco-industry itself of a stricter environmental policy? This thesis attempts to answer these questions focus on examining the drivers behind decision making by industrial polluters and abatement producers.

Abatement is a widely adoption for industrial pollution reduction. As the demand side and the supply side of industrial abatement, polluters' compliance decision and eco-firms' output decision are fundamental related to industrial environmental performance. This thesis examines the drivers behind industrial polluters' compliance when there exists the weak implementation of environmental policy and clarifies the consequence for regulated eco-firms' themselves of a stricter environmental regulation.

Chapter 3 addresses the drivers behind industrial polluters' compliance with environmental regulations. Despite the existence of a large literature on regulatory compliance, ours particular focus is on the relationship between human capital and compliance, which is considered as a neglected aspect of the existing research. In Chapter 3, we have empirically examined the internal and external effects of human capital on environmental compliance by using the real environmental performance data of Chinese industrial firms. Our estimation shows that firms' compliance decisions are not only affected by their internal endowment of human capital, but also impacted by the external stock of social human capital. Firms with high human capital are more likely to have better environmental compliance. The study also finds that a highly educated local population (CCOLLEGE) contributes to firms' environmental performance. In contrast, a low level of education in the local population (CPRIMARY) is associated with poorer compliance. The results are still significant after we give thought to the possible endogeneity of both internal and external human capital. However, for clean industries, our results demonstrate that the variation in external human capital is a better determinant of the firms' environmental performances than the variation in internal human capital. We do not find supporting evidence for the internal effect of human capital in SO_2- related and soot-related clean industries when we decompose our data into dirty and clean sectors by pollution intensity of industries in terms of industrial polluted water emission, industrial SO_2 emission and industrial soot emission.

In addition to these findings, to gauge the relationship between the dirtiness of an industry and its environmental performance, we divide our sample into dirty and relatively clean industrial sectors. One difference between the full sample and that involving dirty and clean industrial sectors is that the internal effect of high human capital (FCOLLEGE) is insignificant in clean sectors of category SO_2 and soot. On the other hand, internal human capital plays an important role in environmental performance of firms in dirty industries. For clean industries, the impact of human capital on environmental compliance is mainly explained by the external effect. It is possible that those clean sectors generate considerably less industrial SO_2 and soot emissions than the relative dirty sectors. In this case, high human capital may not play a notable role in pollution abatement.

The next issue to be addressed in this thesis, in Chapter 4, is eco-firms' output decision in response to a stricter environmental policy. In the existing studies, the regulated eco-industry acts as a policy instrument for pollution control by government; none of them explicitly address the consequence for the eco-industry itself of stringent environmental regulation. The aim, in Chapter 4, is to examine regulatory effect on the market for abatement goods and services. More specifically, we investigate the effect of environmental regulation stringency on industrial abatement demand and individual output of eco-firms. How does the abatement output of an eco-firm respond to a strict environmental policy? What is the consequent impact of industrial abatement volume induced by a strict environmental policy on an eco-firm's output? The analytical study presented in Chapter 4 addresses these questions by constructing a simultaneous model. Taking into account the fact the environmental regulation stringency differs with respect to different kinds of target pollutants, our results have shown that environmental regulation stringency of both industrial SO_2 and industrial wastewater emissions do not only contribute to the improvement of industrial environmental performance but also encourage to the development of eco-firms. With respect to the regulatory effect on industrial abatement demand, though the indirect effect of regulation stringency on industrial abatement volume is negative, the overall effect is positive for both pollutants. Turning to the regulatory effect on individual abatement supply, our results show that environmental regulation stringency of SO_2 fails to impact directly an eco-firm's output; instead, SO_2 regulation stringency can indirectly affect an eco-firm's output through its impact on industrial abatement demand. As for environmental regulation stringency of industrial wastewater, we find that the treatment charges of industrial wastewater can directly and indirectly affect an eco-firm's output decision.

The studies contained in Chapter 2, Chapter 3 and Chapter 4 offer findings that are well-defined and actionable. But more importantly they have clear implications for economic policy. The next section discusses these implications.

5.2 Policy implications

This section discusses the policy implications stemming from two analytical studies that make up this thesis.

Chapter 3 studies the relationship between firms' environmental compliance and human capital and the results yield a number of policy implications. The role of city-wide human capital levels in compliance suggests that there is a positive externality from education. More generally, evidence from this study suggests that the situation of weak implementation of environmental supervision and evasion of environmental monitoring could be improved by means of internal and external human capital. On the regulator side, a strategy of boosting the educational attainment of the population may be recommended to pull firms into better environmental compliance. On the firm side, raising human capital may induce improved environmental performance.

Chapter 4 investigates the effect of environmental regulation stringency on industrial abatement and individual output of eco-firms and the findings offer a number of policy implications. The empirical evidence in Chapter 4 shows that a strict environmental policy stimulates an increase in an eco-firm's abatement output. In general cases, the regulation induced market power effect triggers the greater individual abatement output values of Chinese eco-firms. The treatment charge of industrial wastewater is in the range of 0.2-1.97, and the levy charge of SO2 is in the range of 0.2-1.2 in the sample period. Considering the current situation in China, the emission charges are set too low; raising the charges, is suggested to improve industrial environmental performance and facilitate the development of eco-firms. However, regarding the negative regulation effect of industrial wastewater in sewage treatment sector, the results suggest that simply raising the treatment charge of industrial wastewater might result in lower individual output values of eco-firms in sewage treatment sector.

Besides, regarding the relationship between abatement and environmental regulation stringency, the results differ with respect to industrial SO_2 emissions and industrial wastewater emissions. Accordingly, different policy suggestions are required to balance economic growth and industrial abatement of SO_2 and wastewater. With respect to industrial SO_2 emission control, our results show that though stricter environmental regulation can contribute to the development of eco-firms, there exists a tradeoff between SO_2 abatement and economic growth due to relatively high cost of desulfurization technologies as discussed in section 5.1.3 of Chapter 4. A win-win situation between development of eco-industry and economic growth can be reached only if there are well-designed environmental regulations. It suggests the more tightening regulation of industrial SO_2 should be on the condition that innovation of SO_2 abatement technologies is widely applied in industrial production with low cost. Hence, the alternative strategy should provide more appealing incentive to undertake the innovation of SO_2 abatement technologies and accelerate its transformation into industrial application. Turning to regulatory stringency of industrial wastewater, in general cases, we find that regulation-induced abatement of wastewater not only benefits to economic growth but also contributes to the development of eco-firms. As mentioned previously, the treatment charges for industrial wastewater are set too low to stimulate eco-firms' initiatives for providing abatement goods and services and so higher charges are required to achieve the possibility for ecological-economic win-win solution. But from the standpoint of the development of eco-firms, the negative relationship between environmental regulation stringency and individual abatement output of eco-firms in the sewage treatment sector suggests that the number of eco-firms in the sewage treatment sector should be controlled at a certain level (to relieve the problem brought about by business stealing effect).

5.3 Further Studies

This section provides some thoughts on the extent to which future research can build on this thesis and draw on its findings. The findings presented here on decision making of industrial polluters and abatement producers for controlling industrial pollution offer a number of avenues for further research.

Regarding industrial polluters' environmental performance, although we have established the importance for compliance of external human capital, we do not know the exact route by which higher education levels influence firm behavior. It could be that human capital levels in the regulatory agency track general education level and so city-level human capital is a proxy for the human capital of the environmental agency. Alternatively, it could be that individuals with higher education levels are more sensitive to compliance and/or more efficient in making complaints, lobbying for controls and prompting investigations into compliance. This is an issue that requires further research.

In Chapter 4, although we have examined the effect of environmental regulation stringency on industrial abatement and individual output of eco-firms, we did not take into account the possibility that regulatory effect might differ with respect to different types of abatement goods and services. As indicated by Frondel et al. (2004), industrial polluters might have different abatement selections in response to a more stringent environmental policy set up by the government; they may adopt end-of-pipe technologies or install cleaner production technologies. So environmental stringency might stimulate different market demands for abatement in terms of end-of-pipe technologies and cleaner production technologies, thereby leads to different abatement output. Therefore, it would be interesting to analyze eco-firms' output decision by comparing regulation effects on end-of-pipe abatement and cleaner production abatement.