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Modeling Pollution Control and Performance in China's Provinces

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Abstract: The paper constructs a pollution control performance (PCP) evaluation model by introducing the norm of n-dimensional space. The PCP of 30 China's provinces for the period of 2003–2008 is evaluated based on the model and the factors influencing China's pollution control are further examined. It is found that: (1) China's PCP has improved rapidly but there is a large regional imbalance with the PCP of Eastern China being much better than that of Central and Western China; (2) To improve the level of China's PCP, government policies should consider industrial structure adjustment, restricting industry entries and increased investment in pollution abatement and R&D.

Keywords: Pollution control performance, Technical progress, Spatial distance, Influencing factors

1. Introduction

With rapid industrialization and high economic growth, China's environmental problems have become increasingly serious. In 2009, China discharged 23.4 billion tons of industrial wastewater, of which 4.4 million tons were Chemical Oxygen Demand (COD), and the emissions of SO₂ reached 22.1 million tons, of which industrial SO₂ emissions accounted for 84% (National Bureau of Statistics of China, 1990-2009). China has become one of the most polluted countries in the world, and industrial pollution emissions are the main culprits for China's serious environmental pollution. According to a 2007 World Bank estimate, the annual economic losses caused by air and water pollution accounted for 8%-12% of the country's GDP (The World Bank and State Environmental Protection Administration (P. R. China), 2007).

In order to reduce pollution and achieve a better use of natural resources, the Chinese government adopted a change in its policy discourse towards building a society that is environmentally friendly and resource efficient (Wen, 2005). This demonstrates its willingness to make a serious effort to diminish the country's impact on the natural environment, and to trigger a fundamental change in China's mode of economic development. Effective control of industrial emissions can enhance China's industrial competitiveness, particularly in response to existing and potential international green trade barriers by Europe, US and the other parts of the world in a post-Kyoto world (Liu and Peters, 2011). Is China in a position to protect and continue to expand its markets? Is it on the right track to decrease and control industrial pollution being generated within the country and is it making steady progress across its provinces? Evaluating industrial pollution control of China's provinces can be helpful in

understanding what advances have been made as well as in achieving further improvement in environmental efficiency and optimization of industrial structures.

The seriousness of China's environmental problems has been attracting the attention of many researchers. There is a rich body of literature available related to the efficiency of existing pollution control (You and Xu, 2009), the impact of institutional factors on pollution control (Jiang *et al.*, 2008), regional environmental performance (Wu, 2010), pollution control and eco-industrial developments (Gibbs *et al.*, 2009), and the effects caused by industrial pollution (Wang S. *et al.* , 2008). These studies have provided a range of policy-relevant conclusions and have contributed to the framing of government policies. However, despite the urgent need for serious practical measures to curb pollution, a comprehensive evaluation model that depicts its control at a regional level has not yet been proposed. On the other hand, there are vast differences between China's provinces in terms of wealth, economic development and available resources. These differences often reflect different histories and stages of industrial development, but if China is to achieve a better environmental performance, attention should be given to the smoothing out of such disparities, as well as to the introduction of more stringent regulations.

In order to respond to the need for a better representation and understanding of the seriousness of the pollution problem across China, the present paper aims at providing an evaluation of the pollution control performance across the country's provinces by assessing it against the best available worldwide practices which are used as thresholds to measure whether the present status is excessive or deficient. In order to do this, a pollution control performance (PCP) evaluation model is constructed by introducing the norm of an n-dimensional space, and

an empirical analysis is carried out using data for 30 provinces over the 2003 – 2008. The approach taken is entirely quantitative as the main research question that the authors are trying to answer is not why and how pollution is being generated. There is ample evidence and measures (including the studies mentioned above) pointing out the gravity of the problem. What the paper aims to achieve is equip policy makers with comparative data that depicts the pollution problem across China. We are aware that providing such an assessment of pollution control performance implies many assumptions and also relies on the use of the best available data. However it is hoped that having quantitative, comparative data will be a step in the right direction, and will assist in making informed decisions that could help change the existing situation and gear the country towards becoming more environmentally friendly. It is not enough to achieve good environmental performance in some parts of the country, particularly this is achieved by shifting polluting industries to less prominent or influential provinces. What needs to be done is to improve performance everywhere by adopting, and even improving on, best national and international practices. For an economy where the government holds central power, the outcomes from an evaluation process can be used to help justify specific policies and interventions affecting regional performance.

The rest of the paper is structured as follows. In Section 2, the proposed performance evaluation model for regional pollution control is described. This is followed by detailed explanation of the best available techniques approach that represents the basis for the evaluation. The case study of the 30 Chinese provinces is outlined in Sections 4 and 5, and Section 6 presents an analysis (based on statistical regression) of the factors impacting on China's PCP. Finally, Section 7 summarizes the main findings and discusses some policy

implications from this research.

2. Methods

2.1 The method for the measuring of regional PCP

The method proposed for the measuring of regional PCP is based on the model of spatial distance, calculated by the norm of an n -dimensional space. In general, the norm $\| \square \|: R^n \rightarrow R$ is equivalent to the length of a vector in an n -dimensional space; a metric $d(\square, \square): R^n \times R^n \rightarrow R$ is defined as a distance between two points in R^n . Then, the distance between x and y in an n -dimensional space is $d(x, y) = \|x - y\| (x, y \in R^n)$. The general conditions of a metric $d(\square, \square)$ and a norm $\| \square \|$ are fulfilled (Kelley, 1975).

The parameter $n \in N$ is defined as the number of evaluation indicators for regional PCP, such as industrial COD discharge density and industrial SO_2 concentrations. For a specific region, its state of pollution control (D_s) can be characterized by a specific value c_i for each indicator i ($i = 1, 2, \dots, n$):

$$D_s = \begin{pmatrix} c_1 \\ c_2 \\ \dots \\ c_n \end{pmatrix} \quad (1)$$

For each indicator, an optimal value c_i^{opt} and a threshold value c_i^{limit} can be set. As PCP is often evaluated by pollution emission targets, the minimum levels of pollutant emissions generally mean the optimal control of pollution. Thus we can define c_i^{opt} as the minimum value of each indicator while c_i^{limit} is defined as the maximum acceptable value of each indicator. Depending on the criteria, the optimal value can be equal to zero. In general, the problem is formulated as a minimization problem. Thus, if the optimal value of an indicator is

the upper bound, the value should be transformed in such a way that the target is its minimization. This can be achieved by subtracting the value from a constant which should be large enough to avoid negative numbers. Following Eq. (1), the optimal values of all indicators c_i can be defined as the optimal state of pollution control $D^{opt} \in R^n$:

$$D^{opt} = \begin{pmatrix} c_1^{opt} \\ c_2^{opt} \\ \dots \\ c_n^{opt} \end{pmatrix}, \text{ for } \forall D \in \Theta_D, c_i \geq c_i^{opt} (\forall i \in N) \quad (2)$$

In terms of pollution control state, D^{opt} can be interpreted as the best possible state for the activities of regional pollution control. It could be an unavailable state in practice, but an ideal direction for all pollution control activities. To aggregate all indicators into a single measure of the pollution control state D_s , the indicators must be normalized on the basis of the defined optimal and threshold values with the weighting factors w_i for each indicator c_i :

$$w_i = \frac{1}{c_i^{limit} - c_i^{opt}} \quad (3)$$

Such distance-to-target weighting methods are widely used in lifecycle impact assessment and impact ranking. The methods rank an impact as being more important the further away it is from achieving the desired targets. According to Soest *et al.* (1998), these methods are only suitable for prioritizing environmental issues, but not for a company's investment decisions. Soares *et al.* (2006) compare various weighting methods and indicate that the distance-to-target method can give more emphasis to the geographic aspects of environmental impact categories. The weighting factor for each indicator (pollutant in this case) remains the same across the entire studied sample (Chinese provinces in this case).

For a general comparison of the pollution control state applying the proposed metric,

weighting factors can be used to define the aggregate measure for the acceptable control radius, namely d_{accept} :

$$d_{accept} = \frac{1}{\sum_{i=1}^n w_i} \quad (4)$$

This definition has several advantages in comparison with a normalized measure, which is always equal to 1. By taking the reciprocal of the sum of the weighting factors, the differences of the threshold limit values directly influence the level of regional PCP. A decrease in one indicator c_i^{limit} leads to a decrease of d_{accept} . Hence, the stricter the requirements are, the smaller the scope for acceptable regional pollution control state is.

In order to verify if a regional pollution control state fulfils the legal requirements, normalized weighting factors \hat{w}_i can be calculated:

$$\hat{w}_i = \frac{w_i}{\sum_{i=1}^n w_i} \quad (5)$$

Then the weighting factors are used to define a modified Euclidean norm for calculating the length of a vector which is equivalent to the aggregate value of all indicators c_i :

$$\|D\| = \sqrt{\sum_{i=1}^n (\hat{w}_i [c_i])^2} \quad (6)$$

By applying this norm and taking into account the optimal values as defined by D^{opt} , the distance measure for the characterization of regional PCP can be calculated:

$$d_D = d(D, D^{opt}) = \|D - D^{opt}\| = \sqrt{\sum_{i=1}^n [\hat{w}_i (c_i - c_i^{opt})]^2} \quad (7)$$

Hence, the smaller the d_D , the better the state of regional pollution control is. Using the measure proposed in Eq. (7), we divide the performance of regional pollution control into three

states: desired, warning and critical state, which correspond to areas D_1 , D_2 and D_3 in Fig. 1, respectively. These states fulfill the following constraints:

$$\begin{cases} D \in \Theta_I, & \text{if and only if } c_i^{opt} \leq c_i \leq c_i^{limit}, d_D \leq d_{accept}; D \in \Theta_D \\ D \in \Theta_{II}, & \text{if and only if } c_i^{opt} \leq c_i \leq c_i^{limit}, d_D > d_{accept}; D \in \Theta_D \\ D \in \Theta_{III}, & \text{if and only if } D \notin (\Theta_{II} \cup \Theta_I); D \in \Theta_D \end{cases} \quad (8)$$

Eq. (8) implies:

- When $D \in \Theta_I$, such as D_1 in Fig. 1, the pollution control targets of this region have met the national standard, and the distance from D_1 to D^{opt} is less than d_{accept} . It means that the PCP of this region is in a desired state.
- When $D \in \Theta_{II}$, such as D_2 in Fig. 1, the pollution control targets of this region have reached the national standard. However, the distance from D_1 to D^{opt} is less than d_{accept} . It implies that the pollution control targets are close to the maximum acceptable value of the indicators, and the PCP of this region is in a warning state.
- When $D \in \Theta_{III}$, such as D_3 in Fig. 1, the pollution control targets of this region have exceeded the maximum acceptable value of the indicators and hence the pollutant emission is in a state of non-compliance. The PCP of this region is in a critical state, and this region should be a key target for strengthened enforcement of environmental regulations.

[Insert Figure 1 around here]

Furthermore, the factors affecting PCP can be examined. It is assumed that the contribution f_i of each factor to the pollution control performance is measured by the specific distance d_D . It can be used to indicate which area of controls should be improved when the pollution control performance is not in a desired state. f_i is measured as follows:

$$f_i = \frac{[\hat{w}_i(c_i - c_i^{opt})]^2}{\sum_{j=1}^n [\hat{w}_j(c_j - c_j^{opt})]^2} \quad (9)$$

Following the estimation of regional PCP, factors that affect regional PCP are identified and examined. Eq. (10) gives the function of factors influencing regional PCP:

$$d_D = f(z_1, z_2, \dots, z_j) \quad (10)$$

where z are the factors influencing the pollution control performance.

2.2 The notion of Best Available Techniques (BAT)

A vital aspect of the evaluation model presented above is the way the optimal values for all indicators are defined as they represent the basis against which the assessment occurs. Theoretically such optimal values can be seen as extreme values, such as 100% control or 0 level of pollution; however this is not always practical on the ground. Instead, the approach taken here is to use the notion of Best Available Techniques (BAT), which was proposed by the European Commission's directive on Integrated Pollution Prevention and Control (IPPC-directive 96/61) as a proxy for the optimal value for each indicator (c_i^{opt}). According to the original IPPC-directive 96/61, replaced later by IPPC-directive 2008/1/EC, BAT is defined as '*... the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole*' (European Parliament and the Council of the European Union, 2011, p. 7). Implicit in this definition is the fact that the "best available technique" will change over time as technologies

develop further, environmental standards become more stringent, the ability to monitor and measure pollution improves and regulators become aware of this progress. Moreover the availability of these techniques, which cover technologies, the ways the production processes are organized and the installations are built, should be technically and economically viable. There are numerous guides produced by the individual EU countries on the BAT by industry sector, ranging from manufacturing to chemicals to dairy produce but a central element of the IPPC directive is the exchange of information between Member States at European level.

The results from this information exchange, as well as the lowest emission level of pollutants within the context of BAT, are documented in BAT reference documents (BREFs) which are published by the European IPPC Bureau. The first edition of BREFs was adopted in January 2002, and the first round of BREFs was completed in October 2006 (European IPPC Bureau, 2010). They cover 31 different industries and manufacturing processes, such as manufacturing of organic fine chemicals, textiles industry, waste treatment, production of iron and steel, industrial cooling systems and emissions from storage, to name a few. The adopted optimal value for pollution control in the model is the lowest value for the respective pollution emission stated in the BREFs, irrespectively of the industry mix in a particular Chinese region. In other words, all industries should aim to achieve the minimal (or best available technique) emission level which represents a practical and clearly defined direction for pollution control.

2.3. Variables and data collection

The rapid recent industrial development in the country has caused significant environmental

deterioration generating all types of pollution, including air, water, land, soil, noise, light, visual and thermal. Existing studies however have not yet clearly explained how to comprehensively characterize the overall level of negative environmental effects caused by industrial development. What is of interest in particular are the waste materials generated by industry, namely gas emissions, wastewater (or effluents) and industrial residue (or solid waste)¹. The above model allows for all of them to be included depending on availability of data. We have however made the choice not to include industrial residue as firstly, data about solid waste are often confidential, not available or inaccurate (Yue and Liu, 2009); and secondly, the impact of solid waste is predominantly localized. On the other hand, air pollutants and water pollutants (for which reliable data are available in China) spread quickly over large areas and can potentially have much more pronounced global effects.

The statistical sample used in this research is a panel data for 30 provinces in China covering the period from 2003 to 2008. Using the method proposed in Section 2, SO₂ emission densities, industrial dust emission, COD discharge and industrial ammonia nitrogen discharge in the industrial sector are selected as indicators to evaluate the pollution control performance in China at the regional level. The first two indicators, namely SO₂ concentration and industrial dust are used to characterize air pollution, while the second two, namely COD discharge and industrial ammonia nitrogen discharge characterize effluents.

In order to carry out an assessment, the model requires threshold and optimal values to be

¹ See for example China's policy on the protection of the marine environment, <http://www.china.org.cn/e-white/6/>.

determined. The threshold values (c_i^{limit}) are defined using the Comprehensive Emission Standards for Air Pollutants (GB16297-1996) for industrial SO₂ emission concentration and industrial dust emission concentration and the National Standard of The People's Republic of China – Integrated Wastewater Discharge Standard (GB8978-1996) for industrial COD discharge concentration and industrial ammonia nitrogen discharge concentration.

In addition to studying the regional PCP, the paper seeks to identify the factors affecting regional performance and hence provide guidance for policy makers. There is a range of factors which may influence regional pollution control performance, such as institutional structure, innovation, economic development, foreign investment and environmental protection measures adopted in the region. The selection of these indicators is a very arbitrary process and the issue as to whether there is a way to properly capture the economic, political, social, technological, investment and financial performance of a region is very complex. There is lack of uniformity in the West as represented by the myriads of indicators collected by statistical agencies, such as the Australian Bureau of Statistics or Statistics Canada, at regional (state, province or territory) level.

The situation in a Chinese context is equally compounded (see for example Mao, 1996; Ning and Tang, 2001, Gu *et al.*, 2001). We have opted for an approach that corresponds to China's official development policies (e.g. Development Research Center of the State Council, 2007). The indicators (which should only be treated as proxies for the factors) are briefly described in the following text with the descriptive statistics for each indicator for the 2003–2008 period shown in Table 1.

- Structural factors: The two factors considered are the structure of the economy (i.e. the

contribution of the industrial sector) and ownership. The former is represented by the ratio of industrial value added to the gross regional product value, and the latter is represented by the ratio of the value added of state-owned and state holding industrial enterprises to the value added of state and non-state owned large-scale industrial enterprises. As industry is a major source of pollution, the level of industrialization is important in regional analysis. China's fast industrialization has been marred with pollution problems (e.g. Cao, 2007). The connection between state ownership and pollution control is not as straightforward. According to Tilt (2007: 931-942), the "state-owned behemoths remain to pollute another day because they are vital sources of employment and revenue, because they have symbolic and political value for the state, and because they are actively beyond the regulatory reach of the municipal and district EPBs" [Environmental Protection Bureaus] which are responsible for the enforcement of environmental regulations. The same author also observes that China's stringent environmental regulations are an implementation puzzle and "the enforcement of emissions standards occurs at the intersection of ecology and the economy" (Tilt, 2007: 932). With the opening of the country's economy to large-scale foreign and private investment, local authorities often feel powerless having to apply considerable discretion towards environmental in favor of economic and social priorities.

- Innovation factors: R&D expenditures are usually used to characterize regional innovation capacity. However, there is a time span between R&D input and R&D output. Despite the studies by Cai et al. (2004) and Zhu and Xu, (2005) which investigated the time lag in R&D investment in China, a consensus about its length is yet to appear. The approach taken here is different. In 1985 China introduced a major reform in its science and technology system

by creating a technology market which in essence represents an immediate mechanism for direct transactions between R&D organizations and their industry users (Gu, 1999). We assume that a thriving technology market (namely the trade of patents and relevant technologies) can to a large extent reflect technological progress in a certain region and therefore we use per capita turnover in the technology market to represent regional innovation capacities.

- Economic development factors: GRP (gross regional product) per capita (or per capita total output value) is generally used to characterize the level of regional economic development, as is also the case here.
- Foreign investment factors: The most commonly used indicator to measure foreign investment is the level of foreign direct investment (FDI), and FDI per capita is also used here.
- Environmental protection factors: As discussed earlier, the development and implementation of environmental regulations in China is a very complicated institutional and policy issue which covers a web of relationships between the state, local authorities and industrial enterprises. In many cases the deciding factor becomes pressure from NGOs and civil society. Despite being extremely important, it is extremely difficult to capture these considerations in a quantitative model. The proxy that we have decided to use here is investment in industrial pollution abatement as it is a direct way to curb pollution and reduce environmental impact. This is represented through the ratio of industrial pollution abatement investment to total industrial value added.

3. Results and discussion

3.1 Empirical analysis of regional pollution control performance

Applying the method proposed in Section 2, the overall pollution control performance and the contribution of each specific indicator outlined earlier are calculated for 30 Chinese provinces between 2003 and 2008. Table 1 describes the situation for 2003-2008 and Fig. 2 present the 2003–2008 trends.

As presented in Fig. 2, all levels of pollution emission in China's regions show a downward trend from 2003 to 2008. This indicates that with the increasing prominence of environmental issues and continuous introduction of stringent environmental regulations, the overall level of China's pollution control performance has improved over time.

[Insert Figure 2 around here]

The classification of the Chinese provinces according to their pollution control state from 2003 to 2008 is presented in Table 1. In 2003, all Chinese provinces studied, with the exception of Beijing, Shanghai and Tianjin, were in a critical state. By 2008 this number has decreased from 27 to 8. Despite the need for further environmental improvement measures, there are positive signs that change is already occurring in China. The number of provinces in desired control state (D) has increased from 2 in 2003 to 8 in 2008 period; while the number of provinces in warning control state (W) has increased from 1 to 14, reflecting the continuous improvement of China's pollution control performance.

[Insert Table 1 around here]

In 2008, the 8 provinces in desired control state are all in East China, while the 8 provinces in critical control state are in Central and Western China. The metric for pollution control in East China is significantly lower than that in Central and Western China (see Fig. 2) and this indicates that there are large regional imbalances in China's pollution control. With the fast transfer of heavy polluting industries from the East to the Central and Western regions (Wu, 2010), improving pollution control in Central and Western China is becoming more and more urgent.

The static and dynamic evaluations both show that the level of pollution control in China has improved quickly. However, there is a significant regional imbalance. Despite the fact that the state of pollution control in East China is close to optimal (with only Guangdong, Hebei and Fujian in a warning state), the Central and Western regions are still in a state of excessive air and water pollution discharge. In addition to industrial dust, other pollutants also need to be abated, particularly for the provinces in a critical state. For example, at 67.5% ammonia nitrogen is a major contributing pollutant for Gansu.

3.2 Impact factors of regional pollution control performance

A further aspect of the analysis carried out in this study relates to the impact the regional characteristics of the provinces, as identified above through the five indicators (namely industry structure, ownership, innovation, gross regional product, foreign direct investment and investment in industrial pollution abatement, see also Table 1), have on pollution control. A simple linear regression function in which the dependent variable appears in a logarithmic form (equation 12) is used to estimate this impact. As each series passes the stationarity test

(required to avoid spurious regression related to endogeneity and simultaneity in time series compared to a standard linear function), such a log-linear model can be applied to provide informative results. It is shown as follows:

$$\begin{aligned} \ln d_{it} = & \beta_0 + \beta_1 \ln(piva_{it}) + \beta_2 \ln(pseva_{it}) + \beta_3 \ln(perd_{it}) + \beta_4 \ln(pcgdp_{it}) \\ & + \beta_5 \ln^2(pcgdp_{it}) + \beta_6 \ln(pfdi_{it}) + \beta_7 \ln(pipa_{it}) + \mu_{it} \end{aligned} \quad (12)$$

where d_{it} denotes the measure of pollution control performance of province i in the year t ; $piva_{it}$, $pseva_{it}$, $perd_{it}$, $pcgdp_{it}$, $pfdi_{it}$ and $pipa_{it}$ denote the ratio of industrial value added to GRP, the proportion of value added of state-owned enterprises, turnover per capita in the technology market (defined by the Statistical Yearbook of China as explicitly stated technology transaction amounts between registered contractors), per capita GRP, FDI per capita, the ratio of industrial pollution control investment to industrial value added, respectively; μ_{it} is the random error term. The ordinary least squares (OLS) method is used to estimate the coefficients of equation (12) with the results presented in Table 2. The values of Hausman statistics imply that the fixed effect model should be accepted as the final model.

[Insert Table 2 around here]

Below is a discussion of these results and what they mean for China's pollution control at a regional level.

3.2.1 Structural factors

(1) Although there has always been environmental pollution due to natural and human made causes, it became a problem of global importance with the rapid processes of industrialization that started in the 19th century (Meadows *et al.*, 1971). Changes in the industrial structure of an economy, and particularly the increase in the share of industrial output,

have a direct influence on environmental pollution, and require more attention to pollution control performance. This is exactly the case in China where industrial production is the main source of environmental pollution and hence the main target for pollution control. The regression results show that the estimated coefficient of the proportion of industrial value added is 0.649, and is significant at 1% level, which indicates that the increase of industrial value added, will lead to an increase in China's pollution control distance from best available practices reducing the level of regional pollution control performance. With the acceleration of the industrialization process, without technological change, China's pollution control performance level will decline, and environment pollution will worsen. This is in line with the broad body of literature surrounding environmental Kuznets curves (e.g. Selden and Song, 1994; Grossman and Krueger, 1995).

(2) China's property rights reform and opening the market to private and foreign enterprise ownership have considerable implications for pollution control. In this study, the proportion of state-owned and state holding industrial enterprises to large-scale industrial enterprises, represents the regional property rights structure. The increase in the state-owned and state holding enterprises will improve the performance of regional pollution control. The regression results show that the coefficient of the proportion of state-owned and state holding enterprises is -0.317, and is significant at 1% level. This indicates that the increase in the proportion of state-owned and state holding enterprises will lead to a decrease in China's pollution control distance from best available techniques, thereby enhancing the level of regional pollution control performance (and vice versa).

The implication is that state-owned enterprises are more inclined to strictly abide by the

requirements of environmental laws and standards. On the surface, this finding seems to contradict the widely spread popular perception (backed up by previous research) that China's state-owned enterprises do not conform to environmental regulations, and often opt for the payment of environmental levies (i.e. financial penalties) to compensate for emitted pollution (e.g. Wang and Wheeler, 2005). This has indeed been the case previously, but there have been recent changes that this research was able to capture. Firstly, the share of the state-owned enterprises has steadily declined in the last decade – from around 70% to 45% (Xu, 2010). Hence the bulk of previous research findings in relation to environmental non-compliance were based predominantly on state-owned enterprises (for example the sample used by Wang and Wheeler, 2005 comprised of 90% state-owned enterprises) and this is one of the first studies to compare environmental pollution performance between large state- and non-state owned enterprises. Secondly, the rapid development of non-state owned enterprises, such as township and village enterprises (e.g. Che and Qian, 1998), has been associated with huge environmental problems (Jahiel, 1997; Strizzi and Stranks, 2000; Cao, 2007). In addition, many foreign-funded enterprises are transferring heavy polluting industries to China. Thus, increasing monitoring of enterprises with investment from Hong Kong, Macau and Taiwan, and generally enterprises with foreign investment, is vitally important for China's pollution control, as are the mechanisms for controlling other large non-state owned enterprises.

3.2.2 Innovation factors

Technical progress is the source and impetus for economic growth. Technical progress, including that associated with environmental technologies, not only promotes a rapid increase

in productivity, but also effectively reduces pollution emission (Acosta *et al.*, 2009), thereby improving regional pollution control performance. The regression results show that the coefficient of per capita turnover of technology market is -0.146, and is significant at 1% level, which indicates that technological progress can significantly improve the level of regional pollution control. Despite the fact that we use a very arbitrary proxy for innovation which is not directly related to pollution control, the results of the analysis show that in the case of China there is a very strong correlation between technology development and improved environmental performance.

3.2.3 Economic factors

Since 2000, especially after China's entry into the World Trade Organization (WTO) in November 2001, the country's economy has expanded rapidly, and the standard of living of both urban and rural residents has improved. China's GDP per capita reached more than US\$ 1,000 in 2002, and the figure exceeded US\$ 3,000 in 2009. Accordingly, the society's preference for a clean environment increases gradually. As GDP per capita is commonly used to reflect the level of economic development, this variable is also adopted as an indicator for measuring the influence of the level of economic development on regional pollution control performance. Many scholars, such as Grossman and Krueger (1991) and Panayotou (1993), share the view that although environmental burdens increase along with economic growth, they start to decrease after reaching a particular threshold while economic activity continues to increase. That is, they believe in the existence of an environmental Kuznets curve (EKC), e.g. Diao *et al.* (2008) and Peng and Bao (2006). In order to test whether EKC exists in the case of

China's pollution control, a quadratic term of GDP per capita is introduced into the regression equations.

The regression results show that, the coefficients of GDP per capita and quadratic GDP per capita are 2.159 and -0.108, respectively. Furthermore, they pass the significance tests at 10% and 1% level, respectively. Thus the pollution control curve exhibits an inverted-U shape, which accords with the EKC hypothesis. The inflection point is Yuan 21,925, which is close to other empirical studies on EKC. For example, the inflection point formulated by Diao *et al.* (2008) is Yuan 19,816 while the figure stated in the study by Peng and Bao (2006) is Yuan 22,480. We find that 23 out of the 30 Chinese provinces passed the inflection point in 2008. This implies that people get a stronger will and have more resources to protect the environment, as the economy grows.

3.2.4 Foreign investment factors

The influence of foreign direct investment (FDI) on China's pollution control performance includes technology spillovers and pollution effect. The influence of FDI on China's environmental protection is generally unclear (Cole and Elliott, 2005; Dean *et al.*, 2009; Burger and Karreman, 2010). The results in this study show that FDI has played an important role in enhancing China's pollution control performance. However as foreign direct investment can happen through many channels, including equity joint ventures, cooperative operation enterprises or contractual joint ventures, wholly foreign-owned enterprises, foreign sharing-holding enterprises and joint exploration (Fung *et al.*, 2002), only a small part of it is associated with large-scale enterprises. The average size of the FDI project in China was

US\$1.3 million in 2003 and dropped to US\$300,000 in 2008 (The US-China Business Council, 2011). In 2008 China also imposed a ban on foreign investment in projects that are highly polluting (Wen, 2008). By introducing advanced foreign technologies and environmental management experience, FDI can promote the overall level of pollution control in the country.

3.2.5 Environmental protection efforts

The results in Table 2 show that industrial pollution abatement investment has no significant influence on pollution control performance in the case of China. Despite the opposite being the case for most economies, China is yet to achieve consistent satisfactory results from its environmental protection efforts. For more than 30 years China has adopted a series of environmental regulations for industrial pollution prevention and control, such as compulsory administration means, economic incentives and information disclosure (Huang *et al.*, 2010; Shi and Zhang, 2006). However, environmental outcomes are still unsatisfactory. A host of political, financial and institutional factors are recognized as the main reasons for the low effectiveness of industrial environmental management. They include, for example, the low efficiency of investment funds in industrial pollution treatment, the resistance from enterprises because of economic profit concerns, and the lack of motivation for local regulators to rigorously enforce environment regulations (Beach, 2001; Schollenberger *et al.*, 2008; Wang M. *et al.*, 2008).

4. Conclusions

The question as to what are the key factors impacting on pollution control in China is not

an easy one to tackle. In this study we have opted to use a quantitative model and as with any modeling exercise, the multitude of perspectives and uniqueness of specific circumstances are lost. What the model however has been able to deliver, is an aggregate picture of the pollution abatement trends across the Chinese provinces, particularly as how they compare to world best practices.

In recent years, China has started a deliberate shift towards decarbonizing and cleaning its economy as demonstrated in many policy documents, including its 12th Five-year Plan. What this study has been able to show is that there is already evidence pointing in the right direction towards pollution reduction and that change is occurring at a rapid pace. The constructed model and the regression analysis of China's 30 provinces allowed to identify the factors affecting the country's regional pollution control performance.

We are convinced that there are many individual cases that can be explored further using other methodological approaches (such as case study research or qualitative methods) which will be able to provide a rich tapestry of problems and solutions. This however was outside the aim of this particular study as it aimed at identifying what are the trends. The main conclusions and their implications are outlined below.

- First, although the level of pollution control has improved steadily, China's pollution control performance is still low and displays a tendency for regional imbalance. In 2008, the level of pollution in 22 (of the 30) provinces was below the optimal state. Eight provinces, located in the Central and Western regions of China, discharged pollutants in excessive amounts. At the other end of the spectrum, the eight provinces, which have managed to control pollution in a close to the optimal state, are all located in East China.

- Second, there is a need to better integrate structural adjustments within the country with environmental protection. The regression analysis of the regional pollution control distance shows that only emphasizing industrial growth and ignoring environmental quality will lead to a decline in regional pollution control performance. State ownership has so far contributed positively for reducing the level of pollution but more emphasis should be given to putting measures in place for controlling the environmental performance of all large-scale enterprises.

- Third, more investment in research and technology development can help improve China's environmental performance as technical progress has a direct positive impact on pollution control performance.

- Fourth, economic development significantly promotes the level of regional pollution control performance. The study shows that an EKC exists in China's pollution control, and most Chinese provinces have passed through its inflection point. As the economy grows, people get a stronger desire and have more resources to control pollution, and the performance of pollution control is thereby gradually improved. Thus, economic development is still fundamental to pollution control.

- Fifth, while foreign direct investment should be encouraged, efforts should be made to prevent the impact of polluting and high energy-intensive industries. The results show that the growth of FDI in China can significantly improve the level of regional pollution control performance. With the efforts of the Chinese government to disallow FDI in heavy polluting and high-energy intensive projects, the importance of FDI as a channel for technology and knowledge transfer is likely to increase even further.

- Finally, it is important to strengthen the effectiveness of pollution treatment and the

proper management of pollution abatement funds. According to the findings of this study, there is no evidence that pollution treatment can efficiently improve regional pollution control performance. It is necessary for China's industrial development to improve the pollution control performance by regulating various pollution control measures. Thus, how to improve the level of pollution control performance by adopting a wide range of environmental instruments, is still a conundrum for the Chinese authorities.

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Table 1 Pollution control state of China's provinces, 2003–2008

Region	Province	Pollution control state ^a					
		2003	2004	2005	2006	2007	2008
East China	Beijing	D	D	D	D	D	D
	Shanghai	D	D	D	D	D	D
	Hainan	C	C	D	D	D	D
	Jiangsu	C	C	C	W	W	D
	Tianjin	W	W	W	D	D	D
	Liaoning	C	C	C	C	C	D
	Shandong	C	C	C	W	W	D
	Zhejiang	C	C	C	W	W	D
	Guangdong	C	C	C	C	W	W
	Hebei	C	C	C	C	W	W
Fujian	C	C	C	C	C	W	
Central China	Jilin	C	C	C	C	C	W
	Henan	C	C	C	C	C	W
	Hubei	C	C	C	C	C	W
	Anhui	C	C	C	C	C	W
	Heilongjiang	C	C	C	C	C	W
	Shanxi	C	C	C	C	C	W
	Jiangxi	C	C	C	C	C	C
	Hunan	C	C	C	C	C	C
Western China	Yunnan	C	C	C	C	C	W
	Sichuan	C	C	C	C	W	W
	Inner Mongolia	C	C	C	C	C	W
	Ningxia	C	C	C	C	C	W
	Chongqing	C	C	C	C	C	W
	Shaanxi	C	C	C	C	C	C
	Guizhou	C	C	C	C	C	C
	Qinghai	C	C	C	C	C	C
	Guangxi	C	C	C	C	C	C
	Gansu	C	C	C	C	C	C
Xinjiang	C	C	C	C	C	C	

^a 'D', 'W', 'C' indicate the desired control state, warning control state and critical control state, respectively.

Table 2 Regression results

<i>Variable</i>	<i>Fixed effect</i> ^a	<i>Random effect</i>
<i>ln (piva)</i>	0.649*** (0.128)	0.290 (0.192)
<i>ln (pseva)</i>	-0.317*** (0.104)	0.150 (0.125)
<i>ln (perd)</i>	-0.146*** (0.033)	0.055* (0.032)
<i>ln (pcgdp)</i>	2.159* (1.208)	-0.442 (0.990)
<i>ln² (pcgdp)</i>	-0.108*** (0.062)	-0.035 (0.051)
<i>ln (pfdi)</i>	-0.111** (0.043)	0.052 (0.054)
<i>ln (pipa)</i>	-0.047 (0.045)	-0.035 (0.041)
<i>Adjusted R-squared</i>	0.741	0.730
Observations	180	180
Hausman Test (Chi-Sq. Statistic)		17.270**

^a *, ** and *** indicate the 10%, 5% and 1% level of significance respectively.

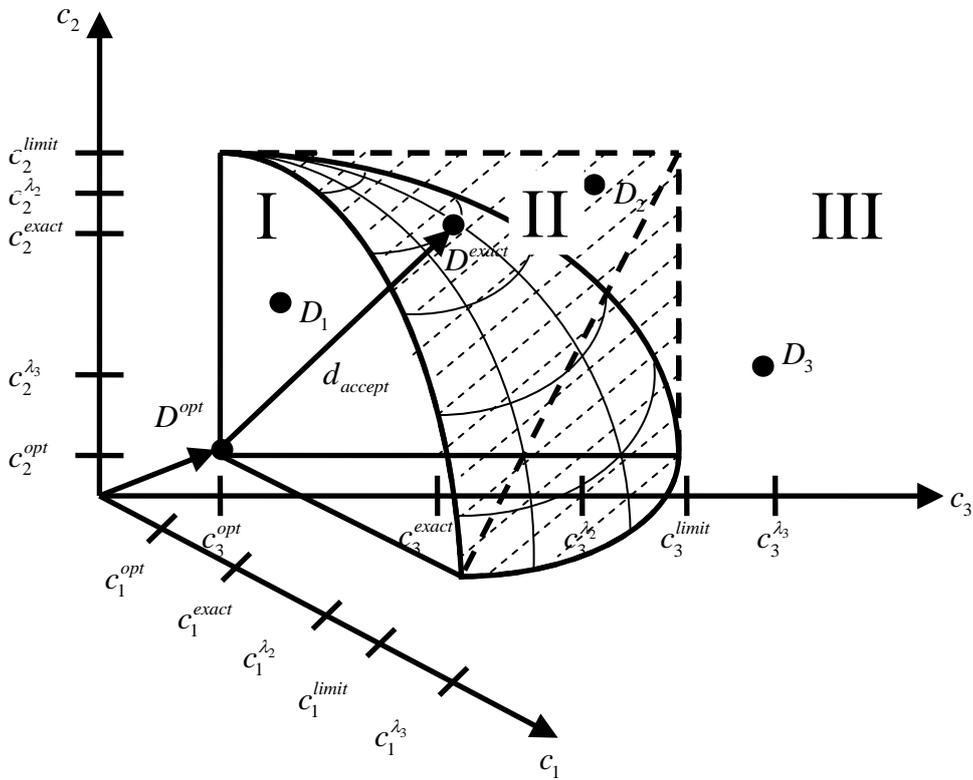


Figure 1. Pollution control state ^a

^a c_1 , c_2 and c_3 indicate the dimensions of PCP which may vary according to different conditions.

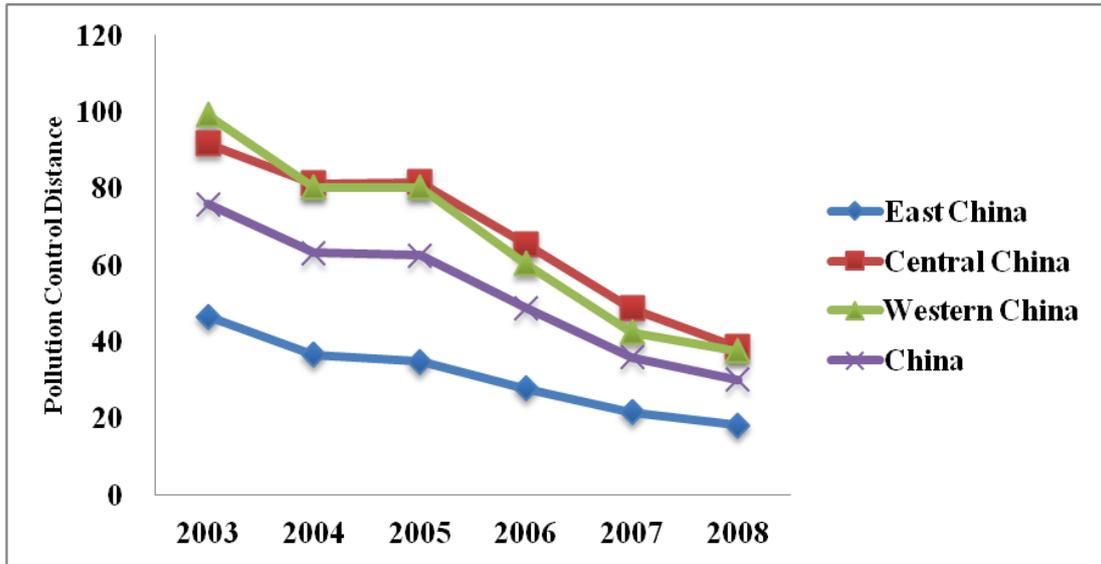


Figure 2. Trends in regional pollution emission levels in China ^a

^a Pollution control distance is a computed index value without units.