

Environmental Efficiency and Its Determinants in China's Regional Economies

Yanrui Wu

Abstract

The increasing awareness of environmental protection has put great pressure on the improvement in environmental regulations in China. How has the current system performed in the nation's rapidly growing economy? The answer to this question is either controversial or yet to be explored in the case of China. The objective of this paper is to present a quantitative analysis of environmental performance in China's regional economies and to examine the determinants of regional variation in performance. The findings are employed to draw policy implications for environmental protection and shed light on sustainable development in China.

Key words Environmental efficiency, environmental regulation, the Chinese economy.

JEL codes O53, Q56, R58

It is well known that China has enjoyed sustained high economic growth since the late 1970s. This growth has put China in the world's spotlight in many ways, both positively and negatively. Environmental pollution is one of the areas which have attracted a lot of attention domestically and internationally. Several events occurred in 2007 have particularly highlighted the seriousness of environmental damages associated with rapid growth for almost three decades in the country. For example, in May 2007, there was a major outbreak of algae in Jiangsu's Lake Tai, which threatened the supply of drinking water to millions of households in the precinct.¹ Subsequently, similar crises occurred in other two large lakes, Lake Chao in Anhui and Lake Dianchi in Yunnan. These algae outbreaks are just the tip of the iceberg, and have once again triggered the environmental alarm in China. They also raise questions about the efficacy of China's environmental regulations which have been implemented for a long time. There is however very little research on this topic.²

This present study attempts to make a contribution to the literature. Specifically, it aims to provide an assessment of environmental efficiency and its determinants among China's regional economies. The rest of the paper begins with a brief review of environmental regulations in China. This is followed by description of the analytical framework employed in this paper. The data issues and empirical model are then discussed. Subsequently, the estimation results and their interpretation are presented. The final section concludes the paper with a summary of the findings and some remarks.

China's Environmental Protection in Practice

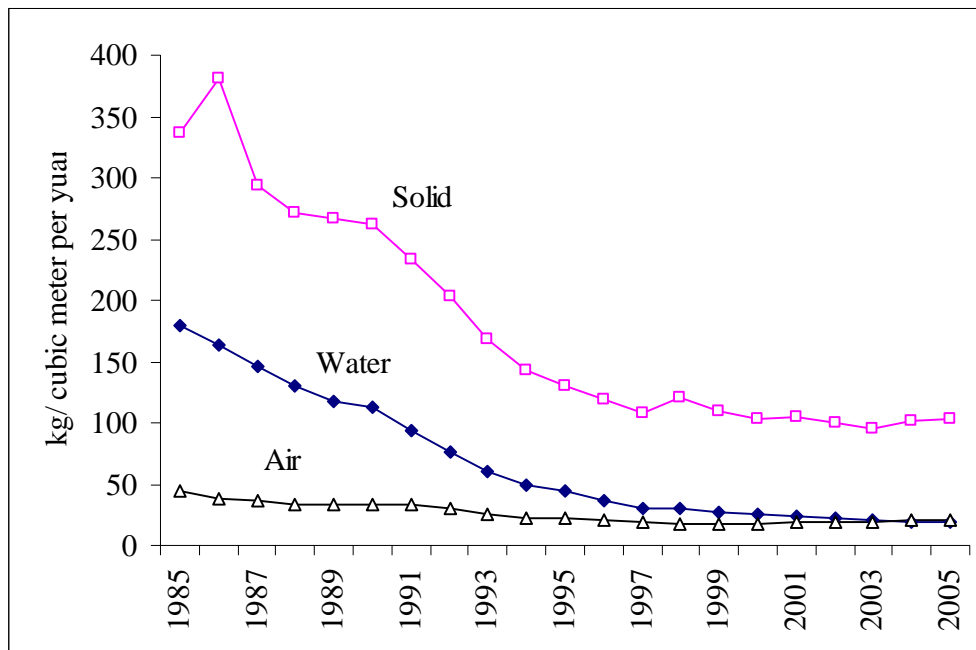
China's environmental protection campaign went back to June 1972 when the then premier Zhou Enlai sent a delegate to attend the Stockholm Conference on the Human Environment. Subsequently, the first national conference on environmental protection was held in August 1973. Since then, China has gradually introduced a series of rules and regulations to protect the nation's natural resources and environment. In 1978 environmental protection was formally incorporated into the revised Chinese Constitution (Article 9, Chapter 1). In the 1980s, more regulations were promulgated for the protection of oceans (in 1982), water (in 1984) and air (in 1987). The environmental law was also enacted in 1989 after its adoption in 1979. Under the guidance of those regulations and laws, the Chinese authority started collecting pollution levy fees on wastes discharged by firms without compliance with the officially designated discharge standards (i.e. above-standard discharges) in the early 1980s. This levy fee system was expanded into a multiple fee system to tax both below-standard and above-standard waste water discharges in the early 1990s. A similar system was also adopted to deal with air pollution in the late 1990s. In the early 1980s, fees collected for the above-standard discharges and emissions accounted for more than 90% of the total pollution levy fees. By 2002, this figure has decreased to about 45%. Thus the Chinese system has shifted to

¹ This story was widely covered by the media such as the Xinhua News Agency (<http://www.xinhuanet.com/environment/>).

² There are however many studies covering China's environment in general. Examples include Dasgupta et al. (2001), World Bank (2001), Wang (2002), He (2006), and Wang and Jin (2007).

charge all polluters with higher levy rates being imposed on discharges or emissions which exceed the official standards.³

Though the stringency of enforcement varies across the regions and industries, the existence of those regulations and laws has contributed significantly to the protection of China's environment. The achievements so far should be acknowledged. For example, the intensity of pollution defined as the amount of wastes generated per unit of output has fallen substantially over the past decades according to Figure 1. In particular, the changes in the intensity of waste water and solids have been dramatic. For example, the intensity of waste water has fallen from its peak figure of 381 kg for every unit of industrial value-added (yuan) in 1986 to 103 kg per unit in 2005.



Sources: China Statistical Yearbook various issues, China Statistics Press, Beijing and China Environment Yearbook various issues, Foreign Language Press, Beijing.

Figure 1 Pollution intensity in China, 1985-2005

In spite of the changes over the decades, China still faces tremendous challenges to protect and improve the country's environment. As shown in Figure 1, the protection of the air is lagging behind. For example, two main industrial pollutants, sulfur dioxide (SO₂) and carbon dioxide (CO₂), are largely discharged into the air. The rapid expansion of car ownership in Chinese households in recent years (from 9.7 millions in 2002 to 23.3 millions in 2006) has further worsened the situation.⁴ As a result, the ambient air quality in many Chinese cities has deteriorated. In addition, there is considerable regional disparity in terms of industrial pollution which is the main source of China's environmental damage. Although the relatively developed coastal areas are the major providers of pollutants, pollution intensity in the less

³ Statistics quoted in this paragraph are drawn from China's Environmental Yearbook (various years).

⁴ China Statistical Abstract 2007, China Statistics Press, Beijing.

developed regions is much higher than that in the coastal areas (Table 1). This is a disturbing development as China's less developed regions, mainly in western China, are more vulnerable to environmental and ecological damages. Since the Chinese authority has shifted its development focus from the coastal to the western region, the environmental consequence should be taken into account seriously before the damages become out of control. The objective of the following sections is to propose a novel technique to examine the overall environmental performance among the regional economies of China, and to understand the determinants of regional performance variation.

Table 1 China's top polluters in 2005

Ranking	Water	Solid	Air
<i>(In terms of discharge shares)</i>			
1	Jiangsu (2)	Hebei (7)	Hebei
2	Guangdong (3)	Shanxi (17)	Shandong
3	Zhejiang (5)	Liaoning (6)	Liaoning
4	Guangxi (21)	Shandong	Jiangsu
5	Shandong (4)	Inner Mongolia (15)	Henan (9)
<i>(In terms of pollution intensity)</i>			
1	Guangxi (21)	Guizhou (27)	Ningxia
2	Ningxia (29)	Shanxi	Inner Mongolia
3	Chongqing (25)	Inner Mongolia	Shanxi
4	Hunan (16)	Jiangxi (22)	Guangxi
5	Fujian (10)	Yunan (23)	Liaoning

Notes: The numbers in parentheses represent GDP rankings of the regions.

Sources: *China Statistical Yearbook 2006*, China Statistics Press, Beijing and *China Environment Yearbook 2006*, Foreign Language Press, Beijing.

Modelling Environmental Efficiency

Various methods have been developed to measure environmental efficiency across countries and within individual economies.⁵ This study employs a technique which belongs to the broader productivity and efficiency analysis literature and which is here extended to deal with pollutants released during the production process.⁶ To introduce the analytical framework, it is assumed that a vector of inputs $x = (x_1, \dots, x_N) \in R_+^N$ are employed to produce a vector of

⁵ For details, see Pittman (1983), Färe et al (1989) and Tyteca (1996).

⁶ For detailed surveys of the productivity and efficiency literature, see Coelli et al (2005) and Kumbahkar and Lovell (2000).

outputs $y = (y_1, \dots, y_M) \in R_+^M$, and a vector of pollutants or undesirable outputs $p = (p_1, \dots, p_H) \in R_+^H$. That is,

$$I(y, p) = \{x \in R_+^N : x \text{ can produce } (y, p)\} \quad (1)$$

where the input set $I(y, p)$ represents the set of all input vectors which can produce the output-pollutant set (y, p) .

Given the definition in equation (1), technical efficiency can be investigated using an input-distance function which can be expressed as

$$D(x; y, p) = \max\{\delta : (x/\delta) \in I(y, p)\} \quad (2)$$

The input-distance function considers by how much the input vector may be proportionally contracted with the output-pollutant vector being fixed. The input-distance function, $D(x; y, p)$, is non-decreasing, positively linearly homogeneous and concave in x , and increasing in y and p . It takes a value which is greater than or equal to one if the input vector is an element of the feasible input set, ie. if production is technically efficient.

In the meantime, environmental efficiency (EE) can be defined as the ratio of the least discharged to the actual amount of pollutants, given technology and the observed levels of output and inputs, that is

$$EE = \min\{\theta : x \text{ can produce } (y, \theta p); x \in I(y, p)\} \leq 1 \quad (3)$$

To empirically estimate models (2) and (3), the property of homogeneity of the input-distance function is exploited. Lovell et al (1994) and Coelli and Perelman (1999) note that homogeneity of degree one in inputs implies that

$$D(\phi x; y, p) = \phi D(x; y, p), \text{ for any } \phi > 0 \quad (4)$$

Thus, if ϕ is arbitrarily chosen to be $1/x_0$, then

$$D(x/x_0; y, p) = D(x; y, p)/x_0 \quad (5)$$

In the translog form, equation (5) can be expressed as

$$\ln D(x/x_0; y, p) = \ln D(x; y, p) - \ln x_0 \quad (6)$$

or

$$-\ln x_0 = \ln D(x/x_0; y, p) + v - \ln D(x; y, p) \quad (7)$$

which is the standard econometric form derived by adding a white noise term v to and rearranging equation (6). In equation (7), replacing $\ln D(x; y, p)$ with u leads to the following conventional stochastic input distance function

$$-\ln x_0 = \ln D(x/x_0; y, p) + v - u \quad (8)$$

where u is a non-negative, truncated error term which captures the effect of technical inefficiency in production.

Given equation (8), the technical efficiency (TE) index can be computed using the following expectation formulae

$$TE = 1 / E[e^u | (v - u)] \quad (9)$$

To derive an index of environmental efficiency, the following two step procedure is executed.⁷ The first step involves the estimation of environmental efficiency scores conditional on the adoption of the best practice technology (hereinafter the best practice environmental efficiency, EE_{BP}). The latter implies that the economy or region considered is both technically and environmentally efficient. Thus, u in equation (8) is set to be zero and

$$-\ln x_0 = \ln D(x/x_0; y, \theta_{BP} p) + v \quad (10)$$

where θ_{BP} is defined in equation (3) and reflects the best practice environmental efficiency. Equations (8) and (10) can then be combined to acquire the following formulae

$$\ln D(x/x_0; y, \theta_{BP} p) - \ln D(x/x_0; y, p) + u = 0 \quad (11)$$

An indicator of the best practice environmental efficiency can be derived by solving the unknown θ_{BP} in equation (11). The detailed process is to be discussed in the empirical section.

In the second step, to reflect the existence of technical inefficiency, an efficiency-adjusted *true* environmental efficiency (hereinafter EE_T) index is defined as follows

$$EE_T = TE \bullet EE_{BP} \quad (12)$$

On the basis of the above estimates, regression analysis can then be applied to examine the determinants of the variation in environmental efficiency among China's regional economies. The actual execution of the regression exercise is conducted later.

⁷ The similar technique was first employed by Reinhard et al (1999) to examine environmental and technical efficiency with environmentally detrimental inputs. Due to their focus on inputs, Reinhard et al (1999) followed an one-step approach.

Data and Empirical Models

The empirical analysis is based on a database of 30 Chinese regions (municipalities and provinces) over the period 2001-2005.⁸ China conducted a comprehensive national economic survey in 2004 and subsequently revised the country's GDP figures including regional statistics. To minimize the potential biases caused by that revision, this study focuses on recent years only. Each Chinese region is assumed to be an economic entity with labour (L) and capital (K) being employed to produce one output ie. the gross regional product (GRP or Y). Three pollutants are also generated during the production process. They are solid wastes (S), waste water (W) and air pollutants (A). The selection of these pollutants is dictated by the availability of regional data. The main sources of the raw data are *Statistical Yearbook of China* and *Environmental Yearbook of China* published annually by the National Bureau of Statistics of China. More detailed description is as follows

- Y : gross regional product in constant prices
- L : total employment in each region
- K : capital stock in constant prices derived by Wu (2007)
- S : solid wastes produced by the industrial sectors
- W : waste water discharged from the industrial sectors
- A : polluted air emissions from the industrial sectors

Summary statistics about these variables are reported in Table 2. In general, all variables have shown an upward trend between 2001 and 2005. There is however substantial variation between the maximum and minimum values reflecting the different size of the regions as well as the existence of regional disparity. Large coastal economies also tend to be the big polluters. This is consistent with observations from Table 1.

Table 2 Summary statistics of the sample

	2001			2005		
	Mean	Max	Min	Mean	Max	Min
Y	100	288(Shanghai)	7(Qinghai)	160	457(Shanghai)	12(Qinghai)
L	21	55(Henan)	2(Qinghai)	23	57(Henan)	3(Qinghai)
K	310	1023(Shanghai)	40(Qinghai)	492	1546(Shanghai)	64(Qinghai)
S	30	88(Henan)	1(Hainan)	45	163(Hebei)	1(Hainan)
W	675	2710(Jiangsu)	44(Qinghai)	810	2963(Jiangsu)	74(Hainan)
A	536	1445(Shandong)	50(Hainan)	897	2652(Hebei)	91(Hainan)

Notes The names in the parentheses indicate the regions which recorded the relevant maximum or minimum values. The units are billion yuan (Y, K), million persons (L), million tons (S, W) and billion cubic meters (A).

⁸ China has thirty-one administrative regions. In this study Tibet is excluded due to missing data.

Given the above-described database, the empirical model can be introduced. In equation (8), let L be x_0 . The empirical version of the stochastic input-distance function is then expressed as follows

$$\begin{aligned}
-\ln L = & \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t \ln(K/L) + \beta_4 t \ln Y + \beta_5 t \ln S + \beta_6 t \ln W + \beta_7 t \ln A \\
& + (\beta_8 + \beta_9 \ln(K/L) + \beta_{10} \ln Y + \beta_{11} \ln S + \beta_{12} \ln W + \beta_{13} \ln A) \ln(K/L) \\
& + \beta_{14} \ln Y + \beta_{15} \ln S + \beta_{16} \ln W + \beta_{17} \ln A + \beta_{18} \ln^2 Y \\
& + \beta_{19} \ln^2 S + \beta_{20} \ln^2 W + \beta_{21} \ln^2 A + (\beta_{22} \ln S + \beta_{23} \ln W + \beta_{24} \ln A) \ln Y \\
& + \beta_{25} \ln S \ln W + \beta_{26} \ln W \ln A + \beta_{27} \ln A \ln S + v - u
\end{aligned} \tag{13}$$

where the subscripts i and t for each variables are omitted for the sake of simplicity, v is the standard white noise with zero mean and constant variance σ_v^2 , and u is assumed to capture the inefficiency effect in the production process. The latter is also assumed to be non-negative, and independent of v . Specifically, it is assumed that $u = \alpha_0 + \alpha_1 t + \varepsilon$ with ε being independently distributed and obtained by truncation of a normal distribution with zero mean and constant variance of σ^2 . Thus, u is obtained by truncation of the normal distribution with mean $\alpha_0 + \alpha_1 t$, and variance of σ^2 .⁹

To derive the environmental efficiency scores, combine equations (11) and (13) to obtain the following reduced quadratic equation

$$a(\ln \theta_{BP})^2 + b \ln \theta_{BP} + c = 0 \tag{14}$$

where

$$\begin{aligned}
a = & \sum_{19}^{21} \beta_i + \sum_{25}^{27} \beta_j \\
b = & \sum_{15}^{17} \beta_i + \sum_5^7 t \beta_j + \sum_{11}^{13} \beta_k \ln(K/L) + \sum_{22}^{24} \beta_l \ln Y \\
& + 2\beta_{19} \ln S + 2\beta_{20} \ln W + 2\beta_{21} \ln A + \beta_{25} \ln(SW) + \beta_{26} \ln(WA) + \beta_{27} \ln(AS) \\
c = & u
\end{aligned}$$

Applying the quadratic root formulae can derive

$$\ln \theta_{BP} = (-b + \sqrt{b^2 - 4ac}) / (2a) \tag{15}$$

and the environmental efficiency indicator

$$EE_{BP} = e^{\ln \theta_{BP}} \tag{16}$$

⁹ Discussion about this type of technical efficiency models can be found in Kumbhakar et al. (1991), Huang and Liu (1994) and Battese and Coelli (1995).

Table 3 Estimation results

	Coefficients	t-values		Coefficients	t-values
β_0	-5.1701	-4.755	β_{18}	0.1395	1.810
β_1	0.1470	1.123	β_{19}	0.0812	2.406
β_2	-0.0022	-0.426	β_{20}	-0.1399	-2.573
β_3	-0.0530	-2.928	β_{21}	0.0879	1.111
β_4	0.0862	3.236	β_{22}	-0.2871	-1.711
β_5	-0.0147	-1.110	β_{23}	0.1019	1.019
β_6	-0.0269	-1.452	β_{24}	-0.2718	-1.387
β_7	-0.0334	-1.256	β_{25}	0.0943	0.802
β_8	-0.5693	-0.907	β_{26}	0.1276	1.024
β_9	0.1878	3.553	β_{27}	-0.0280	-0.389
β_{10}	-0.3751	-3.254			
β_{11}	0.3938	4.811	α_0	0.0438	0.423
β_{12}	-0.0444	-0.516	α_1	0.0081	0.212
β_{13}	0.1590	1.512			
β_{14}	0.7035	1.242	σ^2	0.0160	5.582
β_{15}	-0.3167	-0.523	λ	0.9394	3.999
β_{16}	0.5956	1.336			
β_{17}	-0.8385	-0.933	log-likelihood value		145.86

Note: $\lambda = \sigma^2 / (\sigma_v^2 + \sigma^2)$ and other coefficients are defined in the text. The results in this Table are derived using FRONTIER 4.1 (Coelli 1996).

Interpretation of the Results

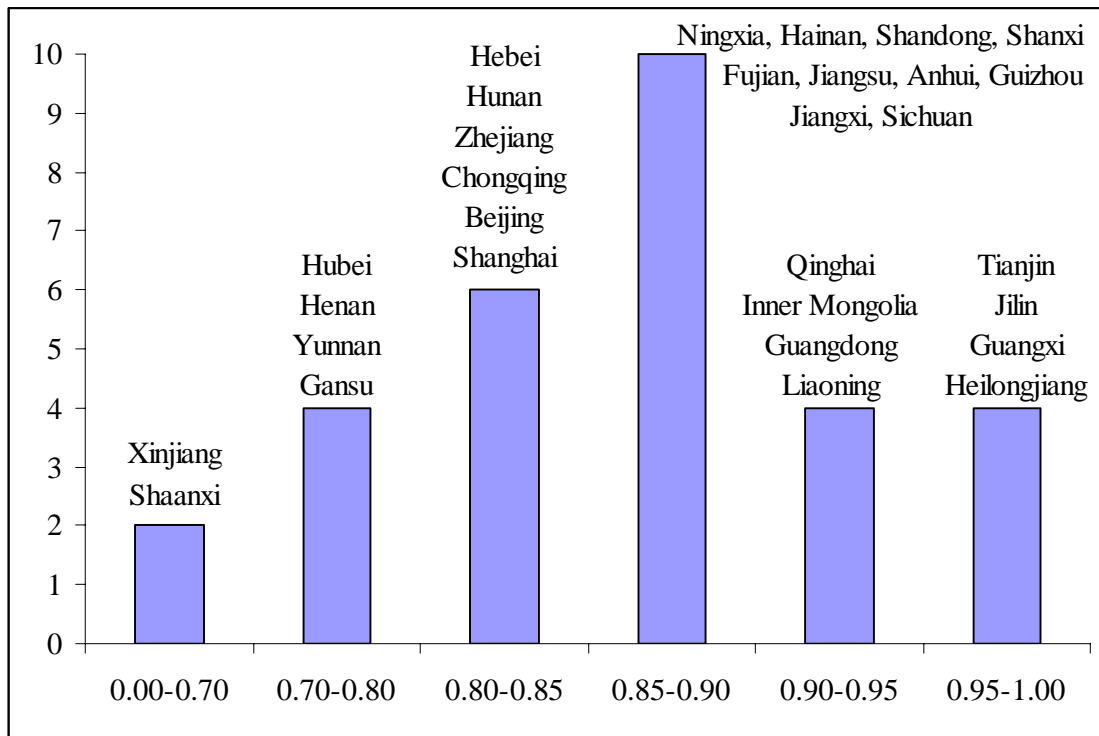
The empirical model of equation (13) can be estimated using the maximum likelihood method (Coelli and Perelman 1999). The results are presented in Table 3. The t -values are mixed ranging from very lower values to the highest 5.582. Both estimates of σ^2 and λ are statistically significant. The value of λ implies that inefficiency has a large contribution to the composite residual of the model. According to the estimates, China's regional economies have achieved an average technical efficiency of 0.88 during 2001-2005. There is thus room for efficiency improvement. In addition, as expected, the coastal regions with a mean technical efficiency score of 90.1% outperformed the rest of the economy.¹⁰ The latter has a mean score of 87.6%.

The estimates in Table 3 are employed to compute EE_{BP} following the process described in equations (14) and (15), and then EE_T using equation (12). On an average environmental

¹⁰ The coastal regions include Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong and Guangdong.

efficiency (EE_T) is estimated to be 85% among China's regional economies. There is however substantial regional disparity (see Figure 2). In general, environmentally more efficient regions include both relatively developed and less developed areas.

Figure 2 Distribution of regional environmental efficiency (EE_T)



Notes: This chart is based on the ranking of the regions' average scores during 2001-2005.

Explaining Environmental Performance

Regional environmental efficiency can be affected by many factors some of which are difficult for quantification. In this exercise, three factors are considered. The first factor reflects the stringency of the enforcement of regulations. The Chinese governments at various levels have promulgated various laws and regulations with regard to environmental protection. The strictness of enforcement however varies among the regions due to complicated reasons. To capture this variation, the proportion of pollution levy fees (*LEVY*) over the value-added in the manufacturing sector has been employed as an explanatory variable in the environmental efficiency regression. It is argued that pollution levy fees as a form of financial penalties may have deterrent impacts on polluters (Wang and Wheeler 2005). Thus, it is anticipated that *LEVY* is positively related to the estimated environmental efficiency indices.

The second factor is associated with environmental awareness (*AWARE*) in the broader community and policy-makers' response to citizens' complaints. It is measured by the number of submissions lodged through members of the National People's Congress (NPC)

and Political Consultation Congress (PCC) over the number of citizens' complaints in each region.¹¹ Complaints from ordinary people and the resultant responses from policy-makers are likely to boost inspections and hence enforcement of regulations (Dasgupta and Wheeler 1997). *AWARE* is also expected to be related to the estimated environmental efficiency scores positively.

The third factor is simply the level of income per capita reflecting the stage of development (*DEV*). In general more developed economies are relatively more environmental friendly and therefore expected to be more efficient environmentally. It is thus argued that some forms of pollution exhibit inverted-U or "Kuznets" relationships with the level of economic development (Selden and Song 1994, Grossman and Krueger 1995). That is, economic development brings an initial phase of deterioration in environmental quality following by a subsequent stage of recovery. In order to test whether there is evidence to support this Kuznets relationship in the Chinese case, both *DEV* and its quadratic form are included in the regression with the environmental efficiency indicator as the dependent variable. If the Kuznets relationship is held, an U-shaped curve is expected (as the depended variable is the environmental efficiency indicator instead of the environmental inefficiency indices).

Thus, in order to examine the determinants of environmental efficiency, the following regression analysis is conducted

$$EE_T = \gamma_0 + \gamma_1 LEVY + \gamma_2 AWARE + \gamma_3 DEV + \gamma_4 DEV^2 + \omega \quad (17)$$

where ω is the standard white noise. The estimation results are illustrated in Table 4. The values of LM and Hausman statistics imply that the random effect model should be accepted as the final model. Table 4 shows that all estimated coefficients from equation (17) are statistically significant and have the expected sign. Thus, environmental regulation and awareness are two important factors for environmental protection. The sign of the coefficients of the income terms (γ_3 and γ_4) implies the existence of a Kuznets relationship. In addition, three extra variables (industrial sector share over gross regional product, share of environmental protection personnel over regional employment and share of investment in environmental protection over gross regional product) are also considered as potential factors affecting environmental efficiency. The estimation results (not reported) failed to show a significant relationship between these factors and environmental efficiency index.

According to the estimates in Table 4, the threshold income per capita is 19,722 yuan at which environmental efficiency (inefficiency) score is bottomed (peaked). This value is equivalent to US\$2,408 according to the market exchange rate in 2005 or \$9635 according to the purchasing power parity rate.¹² It is much smaller than the threshold values derived by other authors though the methods vary. For example, using cross country statistics, Grossman and Krueger (1995) found the threshold level of income to be at least US\$7500 in terms of water quality and Selden and Song (1994) showed a turning point estimate of income which

¹¹ NPC is effectively China's parliament responsible for legislation. PCC is the most influential policy advisory body in China.

¹² Converted using exchange rates of 8.19 yuan/US\$ in 2005 (NBS, 2006) and 2.047 yuan/ppp\$ (IMF 2007).

exceeds US\$8000 in terms of atmospheric concentrations of both suspended particulate matter and sulfur dioxide. Thus, as emerging economies, the Chinese regions may be able to adopt new technologies and hence reach the peak of the invested-U at an earlier stage than the world's developed economies did. This would be encouraging news if the trend continues.

Table 4 The determinants of environmental performance

	Fixed effect		Random effect	
	Coefficients	t-values	Coefficients	t-values
γ_0			0.826560	35.028
γ_1	0.029699	4.117	0.025885	3.728
γ_2	0.002104	2.405	0.001918	2.217
γ_3	-0.004406	-2.414	-0.003195	-1.834
γ_4	0.000099	2.840	0.000081	2.383
\bar{R}^2	0.9022			
LM			221.35 (0.0000)	
Hausman			6.55 (0.1618)	
Sample size	150		150	

Notes: the LM and Hausman statistics report the results of testing the fixed effect model against the conventional regression model (with the latter being rejected) and the random model (the fixed effect model being rejected), respectively. The values in parentheses are the corresponding p -values.

Concluding Remarks

This paper proposes a novel approach to investigate environmental efficiency among China's regional economies. The empirical analysis, using a database of 30 Chinese regions for the period of 2001-2005, shows that Chinese regions on average have achieved 88 per cent of their best practice output and 85 per cent of their environment efficiency. Thus there is still considerable scope for improvement in terms of both technical efficiency (catch-up) and environmental protection. In terms of regional variation, the coastal regions are generally producing closer to their production frontiers than other regions. The coastal regions tend to be the main polluters though they are found to be more efficient in environmental protection. China's non-coastal regions, mainly the interior provinces and border areas, have revealed greater pollution intensity and lower environmental efficiency. This may have serious consequences as China's growth centre and development momentum are shifting towards the non-coastal areas.

The empirical analysis also shows that regional environmental efficiency may be affected by the stringency of the enforcement of regulations and the awareness of environmental protection among the broader communities. Policies strengthening enforcement and promoting environmental awareness should help the control of industrial pollution. Finally, this study also provides evidence of the existence of a Kuznets relationship between pollution and economic development among the Chinese regions. The turning point from the environmental degradation phase to the recovery stage seems to occur at an earlier stage of development in China than that in the world's developed economies. This may be due to China being a latecomer and thus able to lead frog in terms of adopting new technology and protecting the country's environment. If this trend continues, it should be a promising development for China and the rest of the world, and provide a bright prospective for China's sustainable growth in the long run.

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