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Comparative Study on Inter-regional Differences of Economic Growth and Environmental Quality in China

by

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Abstract

A model of economic growth and environmental quality is presented in this paper, which then focuses on measuring the relationship between economic growth and environmental quality for China's four big economic regions. The inter-regional differences among the four areas are also compared. The research results show that the relationships between the three industrial waste emissions and economic growth have not completely followed an environmental Kuznets law, and the results for each region have obvious differences. Factors such as economic growth, industrial structure, technical progress, environmental governance and external openness have different impacts on the environmental quality in the four regions. However, readjustments of industrial structure and technical progress have positive impacts on the environmental quality to all regions.

Keywords: Environmental quality; Economic growth; Regional development.

JEL Classification No.: O40, O53, Q51, Q56.

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1. Introduction

In the past thirty years, China's economic growth has been running on a fast track, at an average annual GDP growth rate above 8%. Now China has become the second largest economy in the world. However, some costs of this rapid economic growth are high energy consumption and high pollution. Data show that total energy consumption of per capita GDP in China is 2.2 times the corresponding average energy consumption of the world in 2010. Of 47 major Chinese cities, the atmospheric environmental quality is beneath the state secondary standard in 33 of them. There are 338 cities that participated in environmental statistics and 137, or 40%, of them have passed only the national third standards on air quality, meaning they belong to the class of seriously polluted cities. At present, acid rain affects more than 30% of China's total land area; China is now the world's third largest heavy acid rain area, behind only Europe and North America. Each year, about a third of industrial wastewater and 90% of domestic sewage pass untreated directly into China's rivers. Consequently, 850 of the more than 1200 monitored rivers in China are heavily polluted; more than 90% of city waters have been contaminated. Fish and shrimp populations have been wiped out in some rivers; and less than a third of China's rivers meet national first and second level water quality standards.

These facts illustrate that the negative impact of rapid economic growth on China's environment is profound. The deteriorating state of environmental quality is extremely worrying. The central and local governments have introduced some mitigating policy measures during the past two decades, but the implementation of environmental protection policies is weak in China. The deteriorating environment poses a serious threat to the sustainable development of the Chinese economy over the long run. As is known to all, economic development levels diverge substantially across China's regions, and environmental conditions also differ widely across regions. The contradictions between economic growth and environmental quality have different dimensions in all regions. The central government in the twelfth five-year plan articulated an over-arching strategy of optimizing distribution, promoting coordinated regional development and building a resource-conserving and environment-friendly society. Therefore, in the context of supporting such a strategy, this paper takes up the important task of presenting a comparative study of the relationship between regional economic development and environmental impact, by analyzing the key factors that influence regional environmental quality. The objective is to identify measures that will help improve regional environmental conditions and promote healthier (sustainable) regional economic development.

In this paper, China is divided into four economic regions: the eastern region, the central region, the western region and the northeastern region. The paper then presents a comparative study of the inter-regional differences of economic growth and environmental quality caused by multiple factors, and analyzes some key factors that affect environmental quality within the four regions. The factors comprise five dimensions: a scale effect, a technique effect, a structural effect, a policy effect and a trade effect. Whether the relationship between the factors and environmental degradation is monotonic or an inverted U-shaped curve is an empirical issue in China. No previous study has tested the environmental Kuznets curve (EKC) of China in these five dimensions because of the difficulty in getting data and the limitation of research ideas. S. Kaneko and S. Managi et al (2009) tested the EKC in China using province level data over the period 1992-2003 and estimated the relationship between income and the environmental quality of wastewater, air pollution and solid waste. Daigee Shaw et al (2010) examined the EKC in China using a panel dataset to compare air quality, income and environmental policy variables for 99 cities from 1992 to 2004. T. Tsurumi and S. Managi (2010) decomposed the determinants of environmental quality into scale, technique and composition effects, and their research results showed that differences in the technique effect were found to play a crucial role in reducing pollution.

The paper consists of five parts, the second part is literature review, the third part is the model and method, the fourth presents the calculation results and analysis, and the final part concludes.

2 Literature review

The existing literature reveals the classical argument that environmental resources will limit the growth of social wealth because of the principle of diminishing marginal returns. Malthus envisaged that the limitations of natural resources would constrain populations. Dennis L. Meadows advanced a "zero growth theory": economic growth must be limited in order to avoid destroying the earth. However, some more optimistic scholars think that environmental limits only temporarily constrain economic growth; technological progress could solve the problem in the long term. Grossman and Krueger (1995), investigating the environmental questions arising from the North American Free Trade Area, first conducted empirical research on the relationship between environmental quality and per capita income, and suggested that the relationship between pollution and per capita income is: "pollution increases with its rise when per capita income is in low level, and declines with its rise when per capita income is in high level". Panayotou (1997) first applied the term “the environmental Kuznets curve” (EKC) to the relationship between environmental quality and per capita income, essentially borrowing the definition from the inverted-U Kuznets curve (1955) between per capita income and income disparity. The EKC reveals there is an inverted-U relationship between environmental quality and per capita income. Subsequently, discussions on the inverted-U relationship between economic growth and environmental quality began.

In most of the research literature, GDP (or GDP per capita) is the indicator used to measure economic growth, and the indicators of environmental quality have been much more varied. Panayotou (1997) used sulfur dioxide emissions to indicate the severity of environmental damage; Carson et al (1997) used sulfur dioxide and nitrogen oxides, carbon monoxide and organic pollutants to describe environmental quality; Stern (2001) used per capita sulfur dioxide emissions to illustrate environment quality conditions; Roca et al (2001) regarded carbon dioxide, methane, nitrous oxide, sulfur dioxide, nitrogen oxides, and the methane volatile organic compounds as indicators to measure environment quality; and Bartz and Kelly (2008)[10] used sulfur dioxide, carbon monoxide, nitrogen oxides and atmospheric suspended solids as indicators to represent the deterioration of environment.

Judging from the model, most of the empirical analysis investigated whether the "inverted-U" relationships exist between the economy and the environment by estimating regression equations with the indicators of economic growth and environmental quality. Through investigating the coefficients of variables in the regression results, the EKC rule between economic growth and environmental quality can be tested. Roca et al (2001) set up logarithmic models on six kinds of air pollutants and economic growth in their empirical research, and found that only sulfur dioxide emissions fell with rising GDP. Costantini and Monni (2008) revised the EKC model using the method of generalized least squares, and found that the revised model had very similar conclusions compare with the traditional EKC results. Managi et al (2009) treated trade and income as endogenous and estimated the overall impact of trade openness on environmental quality using the instrumental variables technique. They had also analyzed the causal effect of trade openness on SO_2, CO_2, and BOD emissions by using extensive annual data for OECD and non-OECD countries. Tsurumi and Managi (2010) examined the determinants of environmental quality by decomposing the relationship and pollution into scale, technique and composition effects using a semi-parametric method of generalized additive models, and their research results showed that technique effect was not enough to reduce CO_2 emissions and energy use at low and middle incomes, except for the case of CO_2 emissions in high-income countries. Kumar and Managi (2010) proposed a productivity index for undesirable outputs such as CO_2 and SO_2 emissions and measured it using data from 51 developed and developing countries over the period 1971-2000. Their results showed that developing countries were catching up to the developed countries in their pollution abatement management, but their catch up was limited because technical progress in developing countries is slower than in developed countries.

In the past, there has been much research on the EKC in China. Scholars' focus has been to verify the EKC and to forecast its inflection point. Li et al (2006) proposed that Guangzhou economic development and environmental changes accorded with an inverse U-shaped EKC. Peng et al (2008) thought that the relationship between Shanghai economic growth and environmental pollution also accorded with the inverted-U shape of the EKC. In recent years, many foreign environmental economists have also done research on the coordination problems between economic growth and environmental quality, and given some warning analyses on the development of the economy and environmental quality. Kaneko and Managi et al (2009) tested the EKC in China with province-level data over the period 1992-2003 and estimated the relationship between income and the environmental quality of wastewater, air pollution and solid waste. They treated the Chinese mainland as a whole, and their research results revealed no significant EKC relationships in China.

Managi and Kaneko (2009) also analyzed how the performance of environmental management had changed over time using nonparametric estimation techniques, and they found that an environmental performance index, abatement effort and increasing returns to pollution abatement play important roles in determining the pollution level over the period 1992-2003. Shaw et al (2010) examined the EKC in China using a panel dataset to comprise air quality, income and environmental policy variables for 99 cities from 1992 to 2004. Their regression results indicated that the EKC hypothesis is supported in the case of SO_2.

To sum up, both domestic and foreign experts have done a lot of theoretical and empirical research on the relationship between China's economy and the environment. Kijima et al (2010) proposed the theoretical models on the EKC mainly included the static models and dynamic models, and any theoretical model should be accompanied with empirical research. The current research status on the EKC in China is that there are two inadequate aspects: first, only per capita GDP has been used as a chief explanatory variable in most of the literature, and other factors influencing the quality of the environment have been manly disregarded. Clearly, environmental pollution should be linked not only with economic growth, but also should consider policy responses, technological progress, changes in industrial structure and so forth. Secondly most experts tested the hypothesis of an inverse U-shaped EKC in China and analyzed the coordinated development of economic growth and environmental quality, using a single province, one city or the national statistical data as samples in empirical research. Only Zhou (2011) made a comparative study on the differences of inter-regional economic growth and environmental quality in China, but she still chose only per capita GDP as a single explanatory variable in her model.
Building on earlier contributions and recognizing the actual situation of China, I make a comparative study on the differences of inter-regional economic growth and environmental quality in China by multifactor, and test the EKC hypothesis in China using five dimensions as explanatory variables in the models. The five dimensions comprise: scale effect, technique effect, structural effect, policy effect and trade effect; the dependent variables are waste water, waste gas and solid waste.

3 Economic growth and environmental quality status

3.1 Economic development situation of the four regions of China

In 1978, China's GDP was 364.5 billion Yuan, and it rose to 30.1 trillion Yuan in 2008. Using comparable prices, the GDP of 2008 is 16.5 times larger than that of 1978. In 2011, China's GDP had reached 6.9 trillion dollars, making China the second largest economy in the world after the United States. Although China's per capita GDP increased nearly 14.2 times from 1979 to 2011, based on International Monetary Fund (IMF, 2011) rankings, it was only the 89th in the world. The growth trend of total GDP and per capita GDP are shown in Figure 1.

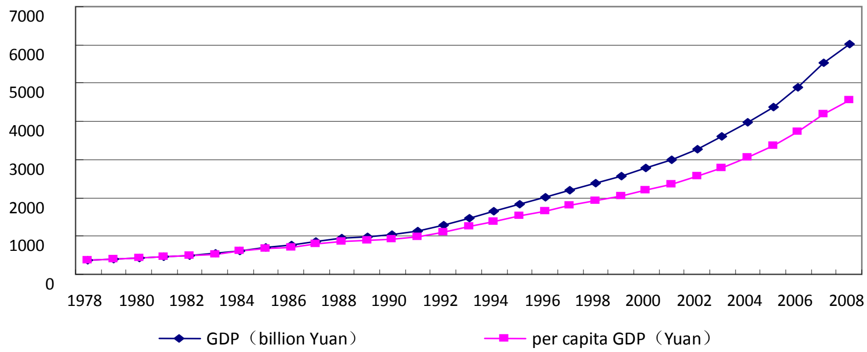

Figure 1：China's economic growth from 1978 to 2008

According to the current practice, the Chinese mainland is divided into four economic regions. They are the eastern region, central region, western region and the northeastern region. The eastern region includes 7 provinces and 3 municipalities directly under the Central Government. The central region includes 6 provinces. The western region includes 11 provinces and a municipality directly under the Central Government. The northeast region includes three provinces.

From a regional perspective, there are big differences in the levels of economic development of the four regions. In 1996, the GDP of the Center, Western and Northeastern together accounted for only 49.7% of the total GDP; the Eastern region accounted for 51.3%. By 2008, the Eastern area GDP reached 55.7% of the total GDP. In 1997, per capita GDP in the eastern region was 9385 RMB and, by 2008, it grew to 37023 RMB with an average annual growth rate of 13.4%. The Northeastern region's per capita GDP grew from 7270 RMB in 1997 to 25929 RMB in 2008, with an average annual growth rate of 12.4%. Per capita GDP in the Western region was the lowest in 1998, at only 3940 RMB, less than 42% of the eastern region and 54.2% of the northeastern region. By 2008, the western region's per capita GDP reached 15950 RMB, only 43.1% of the east and 61.5% of the northeast.

We can see from the above that all four regions have enjoyed rapid economic growth stage since the late 1990's, but differences in total GDP and per capita GDP have gradually widened between the four regions (shown in Figure 2).

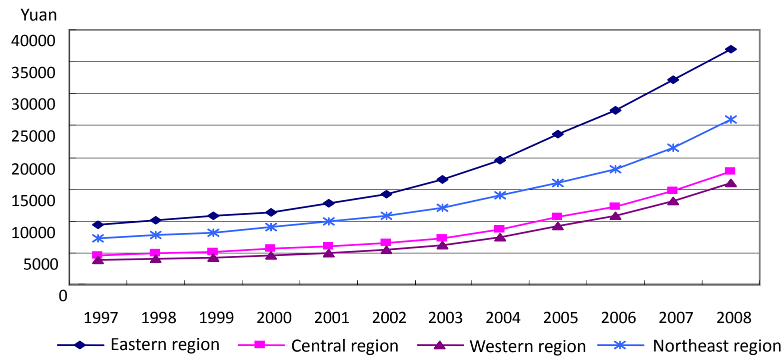

Figure 2：per capita GDP in the four regions

3.2 Environmental quality conditions in the four regions

The fast growth of the economy has been accompanied by a rapid deterioration in China's environmental quality during the past thirty years, and the deterioration still places China on the left side of the EKC. Among the indicators of environmental quality, industrial wastewater emissions have remained at a high level; after trending gradually downward from 1985 to 1997, emissions have resumed an increasing trend since 1997. By studying the evolution of the indicator, we can see that pollution of the water environment is increasingly serious in China.

As shown in Figure 3, industrial waste gas emissions have been rising year after year. The increase was moderate from 1985 to 2000, compared with the sharp acceleration in waste gas emissions curve after 2000; average annual emissions growth rate was at least 24%. Industrial waste gas emissions amounted to 40.39 trillion standard cubic meters in 2008. The situation of air pollution was very grim.

Industrial solid wastes emissions also have been increasing year by year. The emissions were 525.9 million tons in 1985, and 1.91 billion tons in 2008, an increase of 262%. From 1985 to 1999, the industrial solid waste emissions grew moderately at an average annual growth rate of 3.2%. From 2000 to 2008, the curve became steeper, and its annual growth rate suddenly increased to 10.4%. The increasing pressure on the environment from all three sources is shown in Figure 3.

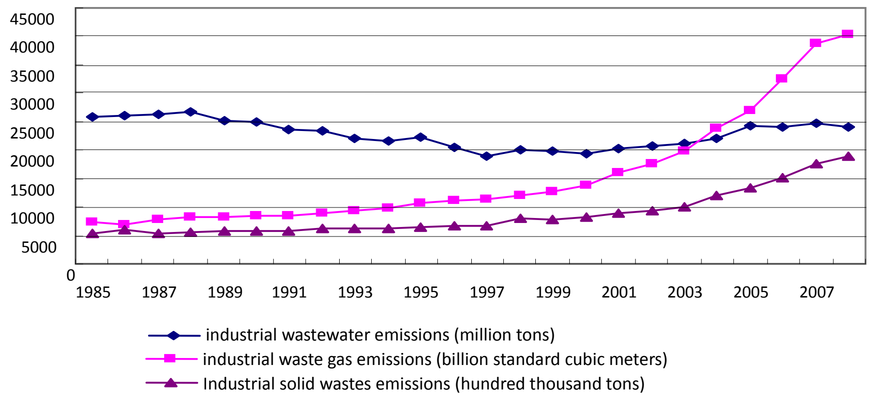

Figure 3: "Three wastes" emissions situation in China from 1985 to 2008

Of the four regions, the wastewater emissions of the Eastern region have been largest and growing fastest. From 1997 to 2008, industrial wastewater emissions increased more than 60% with an average annual growth rate of 4.6% in the eastern region. Industrial wastewater emissions in the central region were in a slow decline from 1997 to 2008 with an annual average rate of 0.15%. Industrial wastewater emissions in the western region presented a kind of slow rising trend with an annual average rate of 3.1%. It is lower than that of the central region before 2003, but it is higher than the center after 2003. Industrial wastewater emissions in the northeast were the lowest of the four regions, and have been declining year by year (see Figure 4).

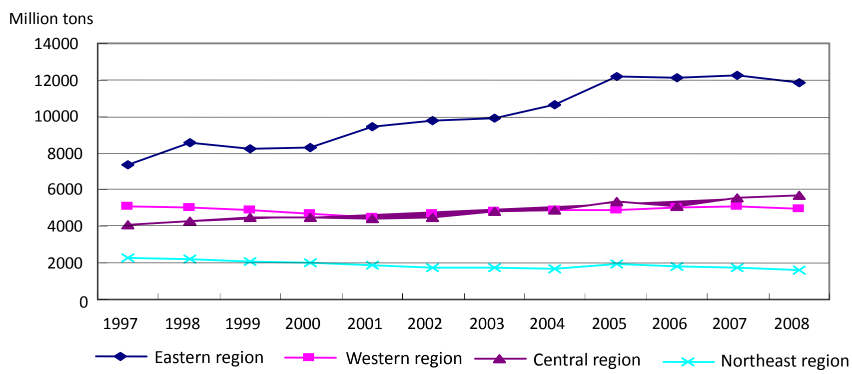

Figure 4: Industrial wastewater emissions in the four regions from 1997 to 2008

As shown in Figure 5, industrial waste gas emissions were rising steeply in all four regions. In the past 10 years, the atmospheric environment emissions of the eastern region have been higher than the other three regions, growing at an average annual rate of 13%. The central industrial waste gas emissions curve is similar to that of the west, and the western curve was higher than the central region in 2004, 2006 and 2007. In the northeast region, industrial waste gas emissions were increasing at an annual average rate of 12.4%, but its total waste gas emissions were lower than those of the other three regions.

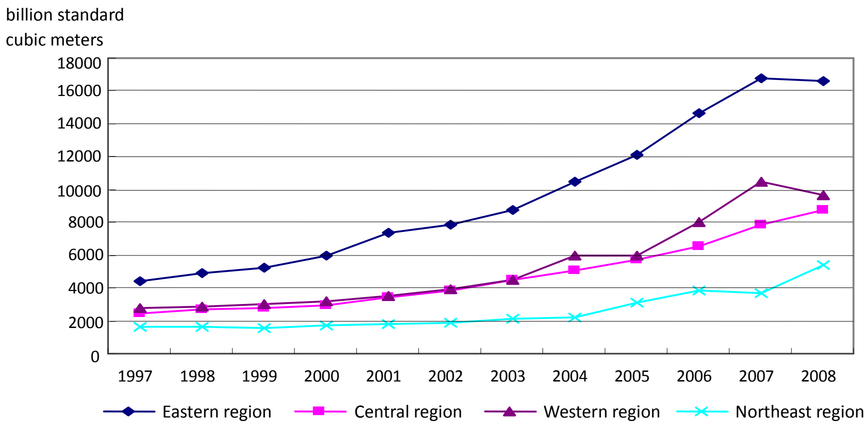

Figure 5: Industrial waste gas emissions in the four regions from 1997 to 2008

Industrial solid waste emissions were on the rise in the four regions from 1997 to 2008. The solid waste emissions of the northeast region were significantly lower than the other three regions; even so, they grew at an annual average rate of 6.8%. The solid waste emissions of the eastern, central and western regions were approximately the same in 1997 and they have grown at similar rates in the ensuing period, respectively at 11.3%, 10.5% and 12% (see Figure 6).

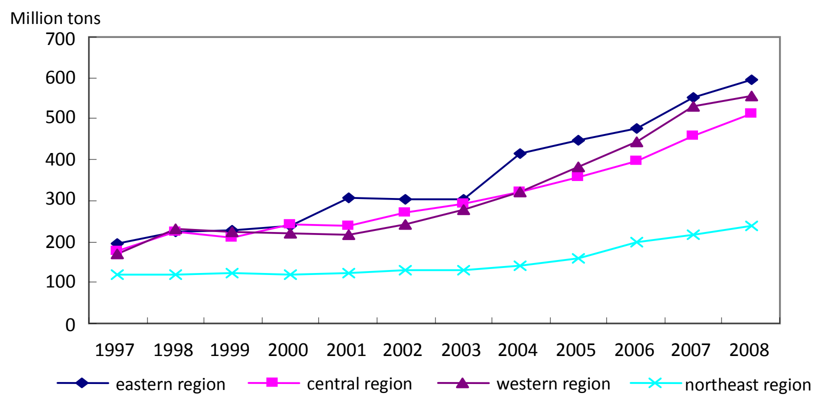

Figure 6: Industrial solid waste emissions in the four regions from 1997 to 2008

Based on the three wastes indicators, the deterioration of the environment has continued in China's regions concurrent with the rapid economic growth of the past thirty years. The changing tendencies were still at the left side of the EKCs, and their turning points have not appeared on the EKCs. An urgent priority is to pay close attention to improving environmental quality in all the regions, identifying the key factors influencing the regional environments, then proposing countermeasures to support sustainable development of the regional economies along with amelioration of environmental damage.

4 Model and Sample Data

4.1 Model

The EKC hypothesis implies that economic growth will eventually lead to improvements in environmental quality (Grossman and Krueger, 1991). Many econometric studies have been made to test the emergence of the EKC in a wide variety of income-based assessments of environmental degradation. Most researchers employ reduced-form models in which the environment-income indicator is a quadratic or cubic function of income. The basic cubic model is:

$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}{}^2 + \beta_3 x_{it}{}^3 + u_{it} \quad (1)$$

Where y_{it} is an environmental quality indicator, x_{it} is per capita income for scale factor, u_{it} denotes an error term. Here while t stands for time, i represents a local area such as a country, province, city or another regional authority responsible for environmental policies. The parameters (β_1, β_2, β_3) are to be estimated from observed data.

Model (1) provides important information as to the form of the relationship between environment and economic growth. Namely, if $\beta_1 > 0$（$\beta_1 < 0$，respectively）while $\beta_2=\beta_3=0$, then there is a monotonically increasing (decreasing) relationship between income x and the environmental indicator y. On the other hand, if $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3=0$, then we observe an inverted-U-shaped relationship, the original EKC pattern. Note that, in this case, the turning point of the curve is given by $x^* = -\beta_1 / 2\beta_2$. Finally, if $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$, we come up with an N-shaped relationship. Of course, when $\beta_1= \beta_2=\beta_3=0$, this indicates that there is no relationship between income x and environment y. Considering other factors that have influence on environmental quality besides per capita income, the basic model can be extended as:

$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}{}^2 + \beta_3 x_{it}{}^3 + \beta_4 Z_{it} + u_{it} \quad (2)$$

where Z_{it} is a vector of other explanatory variables that contribute to environmental degradation, and it includes structural factors, technical factors, policy factors and trade factors. Therefore, we can convert equation (2) to equation (3):

$$E_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}{}^2 + \beta_3 x_{it}{}^3 + \beta_4 ISS_{it} + \beta_5 TPL_{it} + \beta_6 EGP_{it} + OTO_{7it} + u_{it} \quad (3)$$

where E_{it} is the environmental quality indicator y, ISS_{it} is the structural effect, TPL_{it} the technique effect, EGP_{it} the policy effect and OTO_{it} the trade effect, all at time t. Based on the international standard EKC regression model, we convert model (3) to the cubic logarithm polynomial model shown below

$$\ln E_{it} = \alpha_i + \beta_1 \ln x_{it} + \beta_2 \ln x_{it}{}^2 + \beta_3 \ln x_{it}{}^3 + \beta_4 \ln ISS_{it} + \beta_5 \ln TPL_{it} + \beta_6 \ln EGP_{it} + \beta_7 \ln OTO_{7it} + u_{it} \quad (4)$$

Because we respectively study the relationships between economic growth and environmental quality of China's four regions, and for each region, all provinces and municipalities in the region constitute a cross section. We need to look at the variations in each economic and environmental indicator within the cross section unit in the same time series. Therefore, the whole sample data have cross characteristics both cross section and time series, namely comprehensive series data or panel data. In general, the processing of the panel data is solved through establishing the mixed regression model, the fixed effects model and random effects model. The three kinds of models are as follows

The pooled regression model： $y_{it} = \beta_0 + \delta_0 d_t + \beta_1 x_{it1} + ... + \beta_k x_{itk} + a_i + u_{it}$ （5）

where, the unobserved effect a_i and the explanatory variables x_{it} are unrelated, then mixed OLS can generate the same estimator which is consistent with β_1. If a_i and x_{it} are related, the estimated value is biased and inconsistent.

The fixed effects mode: $y_{it} = \beta_0 + \delta_0 d_t + \beta_1 x_{it1} + ... + \beta_k x_{itk} + a_i + u_{it}$ （6）

where, a_i is related with explanatory variables x_{it}, and regarding a_i as an unknown parameter.

The random effects model： $y_{it} = \beta_0 + \beta_1 x_{it1} + ... + \beta_k x_{itk} + a_i + u_{it}$ （7）

where, a_i is a stochastic variable that is assumed to be unrelated to x_{it} .

In the three models, *i* is a cross section unit and *t* is time. The main difference between the three models is the observed effect a_i. In the empirical analysis, we usually judge which kind of model should be established by using the F-test and the Hausman test respectively.

4.2 Variables defined and data description

Environmental quality indicator E_{it} denotes environmental degradation which includes industrial waste water emissions (*IWWE*, ten thousand tons), industrial waste gas emissions (*IWGE*, hundred million standard cubic meters) and industrial solid waste emissions (*ISWE*, ten thousand tons). Choosing these indicators relates to those industries regarded as “pillars” in promoting economic growth in China that are also the main source of environmental pollutants.

The per capita income *x* indicator for scale effect is per capita GDP data here. It can describe objectively the economic growth situation of China. In order to eliminate the influence of the corresponding price level, nominal GDP data have been adjusted with the per capita GDP deflator (base year is 1978).

The industrial structure state (*ISS*) indicator for structural effect is measured by the added value that secondary and tertiary industry contributes to GDP.

The technical progress level (*TPL*) indicator for technique effect is measured by the power consumption per unit GDP (KWH/Yuan).

The environmental governance policy (*EGP*) indicator for policy effect is indicated by the completed annual investment (RMB ten thousand) in pollution treatment projects to measure environmental policy efforts.

The opening to the outside (*OTO*) indicator for the trade effect is measured by the ratio of China’s dependence on foreign trade.

The sample data used are obtained from different sources. They include the *China*

Statistics Yearbook from 1998 to 2010 and the *China Environment Yearbook* from 1998 to 2010. In order to eliminate the sharp fluctuations and the influence of different variances of the sample data, we have already made the natural logarithms processing to the time series data. All the empirical analyses have been finished with the econometric software Eviews6.0, and all the graphics and tables are drawn with Matlab7.0.

5 Calculation results and analysis

We established respectively the mixed regression model, the random effects model and the fixed effects model according to the four regions. Dependent variables are *IWWE*, *IWGE* and *ISWE* and independent variables include x, *ISS*, *TPL*, *EGP* and *OTO* in the models. In order to consider the endogeneity problem of per capita GDP (x) and the other independent variables, we performed Hausman tests. The tests cause us to reject the null hypotheses of exogeneity for these variables. Therefore, we use the instrumental variables approach for per capita GDP and the other independent variables. Finally, the results of the Hausman test show that the hypotheses of the random effects model are rejected for *IWWE*, *IWGE* and *ISWE* except for *IWWE* of the east, and *IWGE* and *ISWE* of the center; and F-test results show that the hypotheses of mixed effects model are refuted for *IWWE*, *IWGE* and *ISWE*. So we only take the random effects model for IWWE of the east, IWGE and ISWE of the center. The other models that were adopted in the four regions for the three dependent variables are the fixed effects models. All the test statistics are shown in Tables 1-3.

Combined with the regression results in Table 1, in the east region, the per capita GDP variable presents a more complex S-shaped curve to the industrial wastewater emissions, and lnx_{it}, $(lnx_{it})^2$ and $(lnx_{it})^3$ are -98.53, 10.23 and -0.35, respectively. The industrial structure variable $lnISS_{3it}$ is -2.13, and it has significant correlation to industrial waste water emissions. This result shows that the optimization of industrial structure, especially promoting the share of tertiary industry to total GDP, will help reduce the industrial waste water emissions. The technical progress variable $lnTPL_{it}$ is 1.18, and it is more significantly correlated with the industrial waste water emissions. This also shows that if power consumption per unit of GDP falls by one unit, industrial waste water emissions will fall by 1.18 units. In addition, the two variables -- environmental governance policy $lnEGP_{it}$ and opening to the outside $lnOTO_{it}$ -- do not affect industrial wastewater emissions significantly. The per capita GDP x and the opening to outside, $lnOTO_{it}$, have no significant correlations to industrial waste water emissions in the center region. The industrial structure variable $lnISS_{3it}$, which is -1.76, is correlation with wastewater emissions, and especially raising the share of tertiary industry will reduce industrial wastewater emissions, but the effect would be weaker than in the eastern region.

The technical progress variable has the same effect as in the eastern region for wastewater emissions, but the impact is lower because power consumption per unit GDP $LnTPL_{it}$ is 0.47. The environmental control variable is -0.03, which shows that increasing investment in environmental governance and protection will reduce wastewater emissions. The fitting results in the western region indicate that per capita GDP presents a more complicated S-shaped correlation to waste water emissions similar to the eastern region. The estimated result for industry organization $lnISS_{2it}$ is 1.83, and indicates that raising the share of secondary industry will increase wastewater emissions; the effect of tertiary industry is insignificant. The variable $lnOTO_{it}$ result is only -0.23 and implies a positive effect. The variables $lnMGP_{it}$ and $lnTPL_{it}$ have no significant correlations with industrial wastewater emissions.

Table 1. Regression results for industrial wastewater emissions in the four regions

	East (Stochastic)	Center (Fixed)	West (Fixed)	Northeast (Fixed)
lnx_{it}	-98.53**		-168.76**	-192.34**
	(2.49)		(2.20)	(4.34)
$(lnx_{it})^2$	10.23**		18.85***	20.53***
	(2.56)		(2.49)	(4.60)
$(lnx_{it})^3$	-0.35**		-0.70***	-0.73***
	(0.09)		(0.09)	(0.16)
$lnISS_{2it}$			1.83***	3.37***
			(0.54)	(0.59)
$lnISS_{3it}$	-2.12**	-1.76**		
	(0.62)	(0.34)		
$lnTPL_{it}$	1.18***	0.47*		
	(0.26)	(0.25)		
$lnEGP_{it}$		-0.03*		
		(0.02)		
$lnOTO_{it}$			-0.23***	-0.14*
			(0.07)	(0.07)
C	328.47*	15.40**	507.34**	600.21*
	(8.09)	(2.23)	(6.49)	(13.53)
adjust R	0.48	0.95	0.44	0.97
F	17.72	187.43	23.60	201.10

*Significant at the 10% level;**significant at the 5% level;***significant at the 1% level

In the Northeast, per capita GDP presents a S-shaped correlation to waste water emissions that is more complicated than is the case in either the east or the west. The estimated result of industry structure $lnISS_{2it}$ is 3.37, indicating that it has a significant negative effect on wastewater emissions as in the west: that is, raising the share of secondary industry will increase wastewater emissions in the Northeast. The variable $lnOTO_{it}$ result is only -0.14, implying a weaker positive effect. Environmental governance and technical progress have no significant correlations with industrial wastewater emissions as in the west.

The regression results in Table 2 show that in the eastern region the per capita GDP variable has a positive correlation with industrial waste gas emissions. The industrial structure variable $lnISS_{2it}$ estimate is 0.86, indicating that a rising share of secondary industry in total GDP will help to reduce industrial waste gas emissions. The technical progress variable $lnTPL_{it}$ result shows that as the power consumption per unit of GDP rises by one unit, industrial waste gas emissions will fall by 0.60 units. The two variables, environmental governance policy $lnEGP_{it}$ and opening to outside $lnOTO_{it}$, have no significant effects on industrial waste gas emissions. The per capita GDP presents a more complicated S-shaped curve for the correlation with waste gas emissions in the center region. The industrial structure variable $lnISS_{3it}$, which is -1.75 has a correlation with waste gas emissions; increasing the share of tertiary industry will reduce industrial waste gas emissions. The environmental control variable result is -0.05, so that increasing investment on environmental governance and protection will reduce waste gas emissions.

Table 2. Regression results for industrial waste gas emissions in the four regions

	East (Fixed)	Center (Stochastic)	West (Fixed)	Northeast (Fixed)
lnx_{it}	1.08***	-116.11**	-60.59***	
	(0.06)	(5.06)	(1.77)	
$(lnx_{it})^2$		13.14**	6.84***	0.09***
		(5.61)	(1.99)	(0.01)
$(lnx_{it})^3$		-0.49**	-0.25***	
		(0.21)	(0.07)	
$lnISS_{2it}$	0.86**		-1.18**	
	(0.32)		(0.47)	
$lnISS_{3it}$		-1.75***		
		(0.27)		
$lnTPL_{it}$	0.60***		0.47***	1.83***
	(0.15)		(0.13)	(0.34)
$lnEGP_{it}$		-0.05*		
t-stat		(0.03)		
$lnOTO_{it}$				
C	-7.96**	352.97**	184.28**	-8.10**
	(0.80)	(15.21)	(5.22)	(2.40)
adjust R	0.98	0.97	0.96	0.97
F	667.34	287.51	206.89	237.82

*Significant at the 10% level;**significant at the 5% level;***significant at the 1% level

The technical progress level $lnTPL_{it}$ and the opening to outside $lnOTO_{it}$ have no significant correlations with waste gas emissions. Fitting results for the western region show per capita GDP exhibits a more complicated S-shaped correlation to waste gas emissions as in the eastern region. The estimated coefficient for industry organization

$lnISS_{2it}$ is 1.18; again, raising the share of secondary industry will increase waste gas emissions. The variable $lnTPL_{it}$ result is 0.47, which implies a positive effect. The $lnMGP_{it}$ and $lnOTO_{it}$ variables again have no significant correlations to industrial waste gas emissions as in the eastern region. In the Northeast, per capita GDP is mildly correlated with waste gas emissions. The estimated coefficient for industry organization $lnISS_{3it}$ indicates no significant ability to reduce waste gas emissions. The result for the variable $lnTPL_{it}$ is 1.83 and implies that power consumption per unit of GDP has a significant positive effect on waste gas emissions. Just as in the east and west the variables environmental governance $lnEGP_{it}$ and opening to outside *lnOTOit* have no significant correlations with industrial waste gas emissions.

As the regression results in Table 3 shown, in the eastern region per capita GDP correlates positively with industrial solid waste emissions. The industrial structure variable $lnISS_{2it}$ estimate is 1.59 again indicating that raising the share of secondary industry in total GDP will increase industrial solid waste emissions. The technical progress variable $lnTPL_{it}$, the environmental governance policy $lnEGP_{it}$ and opening to outside $lnOTO_{it}$ have no significant effects on industrial solid waste emissions. Per capita GDP also is positively correlated with industrial solid waste emissions in the central region as in the eastern region. The coefficient of the industrial structure variable $lnISS_{2it}$ is 2.38; raising the share of secondary industry will reduce more industrial solid waste emissions than in the eastern region.
The environmental control variable result is -0.168, and this shows that increasing investment on environmental governance and protection will reduce solid waste emissions. The technical progress level $lnTPL_{it}$ is 0.428, which shows that it has a positive effect. The opening to outside $lnOTO_{it}$ is -0.155 and the environmental governance $lnEGP_{it}$ is -0.168 and they have positive correlations with solid waste emissions too. The fitting results for the western region show per capita GDP has a positive correlation with industrial solid waste emissions just as in the eastern region and the central region. The variable $lnTPL_{it}$ result is 0.90, also implying a positive effect. The $lnISS_{it}$, $lnMGP_{it}$ and $lnOTO_{it}$ variables have no significant correlations with industrial solid waste emissions. In the northeast, per capita GDP has a mild correlation to solid waste emissions as in the other three regions. The variable $lnTPL_{it}$ result is 1.15, implying that power consumption per unit of GDP has a more significant positive effect on waste gas emissions. The opening to outside *lnOTOit* result is -0.23 also a positive effect. The industrial structure $lnISS_{it}$ and the environmental governance $lnEGP_{it}$ have no significant correlations with industrial solid waste emissions similar to the west.

Table 3. Regression results for industrial solid waste emissions in the four regions

	East (Fixed)	Center (Stochastic)	West (Fixed)	Northeast (Fixed)
lnx_{it}	0.75***	0.71***	0.97***	1.35***
	(0.06)	(0.10)	(0.03)	(0.13)
$(lnx_{it})^2$				
$(lnx_{it})^3$				
$lnISS_{2it}$	1.59***	2.38***		
t-stat	(0.33)	(0.20)		
$lnISS_{3it}$				
$lnTPL_{it}$		0.43***	0.90***	1.15***
		(0.07)	(0.13)	(0.27)
$lnEGP_{it}$		-0.17***		
		(0.03)		
$lnOTO_{it}$		-0.16***		-0.23***
t-stat		(0.06)		(0.07)
C	-5.84*	-5.53**	-5.70**	-8.76***
	(0.89)	(0.47)	(0.68)	(2.54)
adjust R	0.98	0.71	0.97	0.99
F	708.68	38.19	377.18	500.94

*Significant at the 10% level;**significant at the 5% level;***significant at the 1% level

6 Conclusions and policy implications

Based on the empirical studies on environmental quality in China using the per capita GDP indicator as the only explanatory variable, such as in S. Kaneko and S. Managi et al (2009) who used added value of secondary industry, we here included other potentially influential factors in our models. Grossman (1995) thought that economic growth has scale effects, structural effects and technique effects that influence environment quality. T. Tsurumi and S. Managi (2010) decomposed the determinants of environmental quality into scale, technique and composition effects in their joint study. In this paper, I focus on two other effects -- the policy effect and the trade effect. Some conclusions of my study are the same as Grossman (1995), namely that economic growth, industrial structure, and technical factors have different effects to the environment quality, but my extension of the Grossman model suggests that two other factors -- environmental governance policy and openness to foreign trade -- also have (positive) effects on improving environmental quality. This is the new contribution of my paper. A further innovation of this research work is that it examines inter-regional environmental quality differences in China. The main conclusions follow.

(1) The regression results of per capita GDP and the independent variables on environmental quality show that economic growth has not led to positive effects on environmental quality in the four regions of China. Instead, the regions' environmental degradation became more serious in recent years. Emissions of industrial waste gases and industrial solid wastes, particular, are rising (see figures 5-6). At least in the models, the relationship between economic growth and environmental quality is yet to conform to the EKC hypothesis in the four regions of China. This result supports the conclusion of Kaneko and Managi et al (2009), but refutes the conclusions of Li et al (2006) and Peng et al (2008). Therefore, from the viewpoint of sustainable development, the speed of China's economic growth probably has to slow. That is to say, we have to weaken the scale effects of economic growth on environmental degradation. The four economic regions of China all should change their economic growth modes into the harmonious development patterns of economy, society and the natural world. Each region has to change from plundering resources and damaging the environment to accelerate GDP growth to protecting and restoring the natural ecological order in order to achieve sustainable economic growth that preserves environmental quality.

(2) The industrial structure variables in all four regions have a positive influence on environmental quality, but their effects differ. This conclusion has some similarities to Shaw et al (2010). The results indicate that the structural effects are not apparent for industrial solid waste emissions as dependent variables in the west and northeast, but they have clear, positive effects in the eastern and central regions. The main reason for no significant effects in the west and the northeast is because the scale of tertiary industry has changed little; as the scale of primary industry falls that of secondary is rising. No matter which region, optimization of the industrial structure has positive effects in improving environmental quality in the long term. Therefore, officials should give full play to structural changes that effect improvements in environmental quality, which is the desirable future trend of development. China's governments should adjust their regional economic policies, and should promote the development of modern service industries by optimizing industrial structure and eliminating low productivity industries. The eastern region and the central region should continue to pay special attention to industrial upgrading, optimizing industrial structure and developing new strategic industries. In the development of the western region and the rejuvenation of the northeastern region, local officials should actively promote their tertiary industries, to complement the ongoing development of primary and secondary industry.

(3) Technological progress has a significant positive technique effect on environmental quality in all four regions. Therefore, the path of low carbon, energy saving, recycling and green innovation is the inevitable choice to establish economically sustainable development and environmentally friendly outcomes in all regions. An important priority for government decision-makers is to foster scientific research and to increase R&D investment, as a spur to technological innovation and the development of high-tech industries, especially in western and central China.

(4) The openness variable for trade effects plays a more positive role in improving

environmental quality in central and northeastern China. These two regions should implement more policies favorable to the participation in global markets and the associated international competition and cooperation. At the same time, East and the West should exploit their comparative advantages to allocate resources efficiently and promote the benign effects of economic growth on the environment that are encouraged by the trade effect.

(5) The environmental governance variable for policy effects has a potentially important part to play. Negative externalities must be constrained by economic and legal means. Regression results show that environmental governance policies produce different positive effects on environmental quality in China’s four regions but, in fact, these effects were insignificant in the four regions over the past two decades. The government decision makers and supervision departments need to review their governance policies and pay more attention to environmental supervision and protection if they are to succeed in halting environmental deterioration.

Researching inter-regional environment quality differences in China is a difficult job and there are several limitations in my study. For example, three factors-- population scale, industrial transfer and urbanization--are not directly considered in the model. I think that per capita GDP and industrial structure overlap in certain respects. Continuing growth in population will lead to greater pressure on the resource base in the long run, which might constrain growth in per capita GDP. Industrial transfer has the potential further to worsen environmental quality in the underdeveloped regions. One might consider the industrial transfer from developed countries to China as an important factor contributing to environmental deterioration in China during the past three decades. The negative effects of industrial transfer on environmental quality between China's regions have been shown in varying degrees. In addition, urbanization has a pronounced effect on climate change and it is also an important factor in despoiling the environment. So, these factors should be considered further in my future study as they will make the models more scientific and realistic.

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