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Economic Growth and Water Pollution in the Circum-Bohai-Sea Zone in China - An Environmental Kuznets Curve Analysis

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June 8, 2020

Declaration of Originality

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Abstract

Based on the principle and model of Environmental Kuznets Curve (EKC), the present paper examines the relationship between water pollution and economic growth in the Circum-Bohai-Sea Zone of Beijing, Tianjin, Hebei Province, Shandong Province, and Liaoning Province with the annual time series data for 2003 to 2017. By analyzing the industrial, household, and total wastewater discharge separately as the measurement of water pollution, the results are consistent with the EKC model. In particular, according to econometric analysis, the variables of economic growth and per capita GDP are statistically significant in domestic and total wastewater discharge cases. However, the association of industrial wastewater discharge and economic development is more significant in the N-type EKC model, according to estimation results. This implies that water pollution will worsen without increased government interventions and management. The sub-goal is to investigate the impact of technologies on the EKC model in each subregion. By using the number of universities as a proxy of technology and observing the turning point, it can be assumed that technology can help decrease the level of water pollution, though trends in Shandong Province challenge this finding.

Keyword: Environmental Kuznets Curves, Technological Innovation, Water Pollution, Economic Development, Econometric Modeling, Circum-Bohai-Sea Zone

JEL Classification: Q52, Q53, Q55, Q56, C52, R11

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1 Introduction

Clean water is an essential part of life and the lifeblood of an economy. However, 1.1 billion people lack access to water, and 2.7 billion experience water scarcity at least one month a year. According to the World Wildlife Fund (WWF), by 2025, two-thirds of the world's population may be facing water shortages. China is no exception. In rural China, over 300 million people do not have access to clean drinking water, and by 2030, forecasts suggest that China will have nearly 200 billion cubic meters of water deficit (Shen, 2011).

While climate change is a critical factor that causes water shortage and droughts in some areas and floods in others, water use from economic growth has played an increasing role in the water scarcity and the deterioration of the water quality. In China, a significant cause of the water crisis is the industrial waste into the river water system.

An example of the industrial pollution of water in China is in the Bohai Rim region, an industrial center of northern China. With its rich maritime resources, complete manufacturing system, and many advantageous enterprises, Bohai Rim is an important part of the national economy. In fact, the total value of the maritime economy has increased by about 10% of the total domestic product (GDP) between 2002 to 2017 (To Lee, 2018). Currently, the industry causes serious water pollution that contaminates the sea. For example, based on an observation of the state of marine life in Hebei Province in 2014—one of the provinces that is part of the Bohai Rim—there is a 72% sewage failure: this means that the water quality that went to the sea failed to satisfy the required standards (Press Trust of India [PTI], 2015). Dou and Zhang (2019) state that industrial, domestic, and comprehensive pollution are the mainland-based sources of contamination that have the largest negative impact on the offshore marine environment. The tension between economic growth and marine environment pollution has become a pressing issue for the Chinese government.

There is a significant amount of literature on the relationship between general environmental degradation and the income level (GDP) in an economy. A representative study is Grossman and Krueger (1995), which examines empirically the relationship between per capita income and various environmental indicators, including urban air pollution, the state of the oxygen regime in river basins, fecal contamination of river basins, and the contamination of river basins by heavy metals. Past research has found that, for most indicators, economic growth brings an initial phase of deterioration followed by a subsequent phase of improvement. The turning points for the different pollutants vary. However, in most cases, they come before a country reaches a per capita income of $8,000USD. This observation is often dubbed 'the environmental Kuznets curve (EKC)' (Agarwal, 2018). The EKC model hypothesizes that there is a certain relationship between economic growth and environmental pollution. It claims that, though the economy would grow with pollution, once the pollution hit the inflection point, the two phenomena would have a negative relationship. At this point, pollution will decrease as the economy grows. This is known as the EKC hypothesis.

Most of the EKC hypothesis testing are done in the developed countries. This is because the per capita incomes in most of the developed countries have long passed $8,000USD, which is the level of the per capita income in Grossman and Krueger (1995). Moreover, some of the environmental indicators in the developed countries have improved during their economic development. It is generally accepted that the EKC hypothesis is largely true and that economic progress will advance people's living conditions rather than be a threat to the environment (Stern, 2004).

Since developing countries, including China, have contributed increasingly to the environmental deterioration during their rapid economic growth, it is natural to investigate whether the EKC hypothesis still holds true in these contexts. However, recent studies regarding developing countries have challenged this assumption. In developing countries, some policymakers hold attitude that oppose "the conventional EKC" because the shape of EKC curve cannot be achieved. For example, Stern (2004) suggests that relying too much on the EKC model may be counterproductive as it could worsen pollution and because the relationship between the emissions and income varies in different countries, even if they adopt the same innovations at the same time.

Thus, Stern (2004) argues that the alternative approaches, such as ‘develop and clean at the same time’, are more efficient in decreasing environmental stress due to pollution. Facing the rapid industrialization that leads to the environmental degradation in China, the Asian Development Bank (2020)[1] recommends that People’s Republic of China (PRC) make a list of strategies for public and private partnerships to tackle environmental challenges. This is consistent with the goals outlined by the Environmental Protection Industry (EPI), which advocates for global policies such as environmental subsidies, rehabilitation, and recycling. The demand side of environmental protection mainly focuses on the provision of urban infrastructure and industrial need. The cooperation between government and the private sector participation can stir up the opportunities for environmental protection firms, both nationally and internationally. The supply side encourages private participants to enter the EPI by establishing market information, putting efforts to monitor and improve the systems, adopting “green finance,” and increasing the scientific, technical research, and development results. Promoting the policy reforms, including developing the emerging industries and formal standards for EPIs, is good for environmental sustainability.

In China, water pollution is a major issue for environmental degradation, and the EKC model can be used to study the water resource conditions and economic growth. Since the region around Bohai is an essential part in the Chinese economy, it is natural to test or examine the EKC hypothesis for this regional economy. To analyze the relationship between economic development and water pollution in the Circum-Bohai-Sea Zone, the

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[1] Baluga, Anthony (2020) contributes to the paper ”Leveraging Private Sector Participation to Boost Environmental Protection in the People’s Republic of China” of the Asian Development Bank (ADB) Breifs.

present study adopts the principle of the EKC model, which relates to the impact of technologies and the policies relating to environmental protection. The results aim to underscore the importance of decreasing the contamination of water and promoting the sustainable economic growth.

The structure of this paper is organized in several discrete sections. Section 1 outlines the purpose and background for this study. Section 2 provides a review of the current literature on economic growth, its relationship with environmental pollution, and the strategies and econometric models used in examining the EKC. Section 3 explains the rationale explaining why I chose the Circum-Bohai-Sea for this study. Section 4 presents the data and the variables that are used in this study. Section 5 builds three simple econometric models based on the EKC theory and investigates the correlation between sewage discharge and economic situation. I improved the model to achieve more reliable outcomes. Section 6 describes the EKC graphs for the three models. Section 7 compares the different subregions' curves and their technologies to see the impact of technological progress. Finally, Section 8 summarizes the results of this study and identifies their policy implications.

2 Literature Review

There are numerous theoretical and empirical studies that examine the EKC model of water quality and economic development in various regions of the world. Liu (2019) studied the industrial and urban wastewater discharge as two predictive variables in Hubei Province. He showed that both the industrial and urban wastewater had a significant inverted U-shaped relationship with per capita GDP as the economy develops.

However, there are opposing views about applying EKC hypothesis. For example, Choi et al. (2015) examined the four main rivers in South Korea. To estimate the water quality, they considered per capita GDP, trade, and population as explanatory factors. The water quality can be represented by either biochemical oxygen demand (BOD) or chemical oxygen demand (COD). In addition, a fixed-effects model was used to demonstrate that both BOD and COD from the nationally pooled data were consistent with the EKC hypothesis; however, the four rivers have dissimilar status. For instance, the BOD and COD of the Han river area are negatively associated with per capita GDP, thanks to the policy of South Korea. The policy improves the water quality as the country becomes more prosperous.

Similarly, Shi et al. (2010) built the econometric model to evaluate the economic growth and environmental pollution in Tangshan, a city in Hebei Province, from 2000 to 2009. The significant environmental pollution indicators chosen were industrial wastewater discharge, industrial waste gas emission, industrial solid waste produce, and industrial dark matter emission. They showed that the industrial waste gas emission variable not only fits well, but also satisfies the EKC trends. The industrial dark matter emission factor has been across the inflection point of EKC model, showing a downward trend. This is due to the "green Tangshan, economic Tangshan" program, which has been operating in recent years and has significantly improved the emission of industrial dark matter. However, the emissions of industrial wastewater and industrial solid waste have an inverted "N" type, which demonstrates that the pollution initially rose but then decreased before increasing again. Therefore, industrial wastewater discharge continues to rise. This underscores that policies are vital to improving the environmental quality and that effective policy can control and limit the deterioration of the ecosystem.

Therefore, it is not always the case that the traditional inverted-U environmental Kuznets Curve is observed. Often, various other models appear, such as the linear regression, U-shaped, or N-shaped models. Dasgupta et. al. (2002) proposed that the shape of environmental Kuznets Curve may vary from the inverted-U shape. They proposed four typical types of shapes, including the classical EKC. The second type, "New Toxics," occurs when industrial societies generate new pollutants when income increases, causing the curve to continuously increase between pollution and income per capita. The third shape, “Race to the Bottom,” is a curve that will rise constantly and then maintain a horizontal line at maximum existing pollution levels. The last model is the “revised EKC,” which is an optimistic view that suggests that the level of the curve will shift to the left. Compared with the “conventional EKC,” the pollution will fall at a lower income level. Specifically, the authors analyzed several aspects impacting the environment to get alternative approaches for improvement. For example, the role of environmental regulation in developing and developed countries demonstrated that regulation is the dominant factor with respect to declines in pollution as countries grow beyond middle-income status. As well, innovations have generated significantly cleaner technologies under economic liberalization. Ultimately, Dasgupta et al. (2002) concluded that growing public concern and research about environmental quality and regulations can lower the Kuznets curve and flatten it before reaching the “revised EKC.”

Based on previous research, it is now clear that regulation policies and technologies can improve the environment quality in the long term. In China, because water pollution always occurs in various local regions, it is more relevant to analyze the EKC curve for a city or a province instead of the whole country. This paper provides an analysis of a particular area around the Bohai Sea, an area that is rich both economically and environmentally, and investigates the relationship between water pollution and economic development. The paper also examines how technologies influence the Kuznets curves.

3 Study Area

Generally, the Bohai Economic Rim (REM) is an inland trade zone surrounding Beijing, Tianjin, Shandong Province, Hebei Province, and Liaoning Province, which represents the economic power of northern of China. In addition, these areas can effectively demonstrate the trend of marine economic development and environmental pollution.

Beijing is the capital of China and a metropolis in northern China. Tianjin is the sixth largest city in China in terms of urban population, and it is a manufacturing center of northern China. Hebei is a province in northern China and has many traditional industries. Liaoning and Shandong Provinces are another two provinces in northern China that are close to Tianjin, Beijing, and Hebei. These cities and provinces are studied in this paper. Their geographical locations are shown in Fig. 1 below.

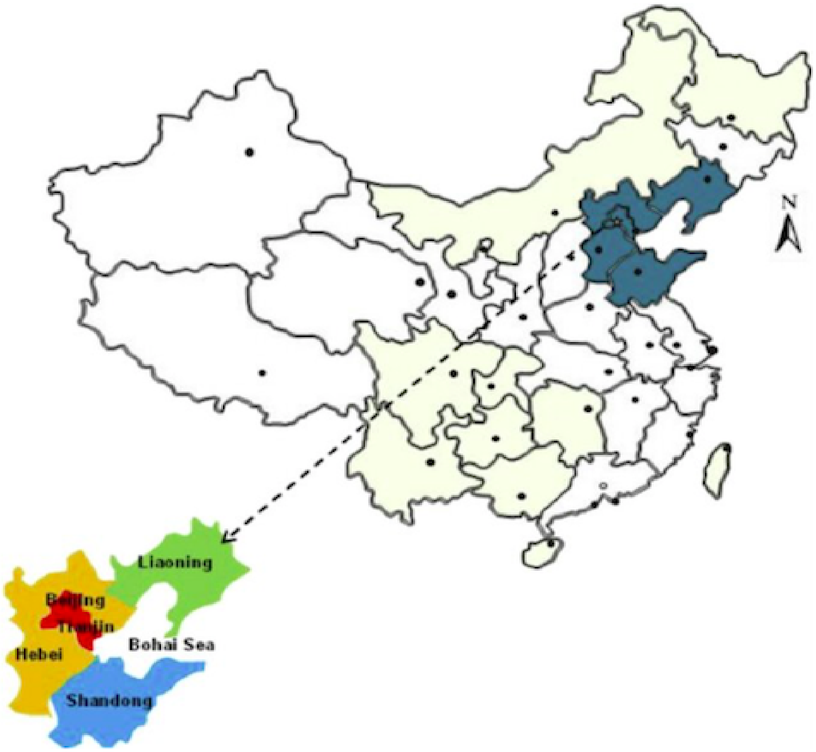

Figure 1: The Circum-Bohai-Sea Zone

The GDPs of these areas have been rapidly increasing for the past three decades. These areas expand through 12% of China's land area and 20% of its population, including Shanxi province and cities in central and eastern Inner Mongolia (Bohai Economic Rim, 2018). Some economists think of the Bohai Sea as the third growth point of the Chinese economy, following the Pearl River Delta and the Yangtze River Delta.

As seen in Fig. 2 below, the GDP per capita of these regions is nearly exponential in growth. For instance, there is an upward trend in Beijing, which grew from 32,061 GDP per capita (Chinese Yuan) in 2003 to 129,000 (Chinese Yuan) in 2017. This is nearly a 400% increase. The GDP per capita of Tianjin also rose considerably, and the GDP per capita of Tianjin is higher than Beijing in the period from 2011 to 2016. Though Hebei Province has likewise seen growth, it's GDP per capita is lower than that of other areas.

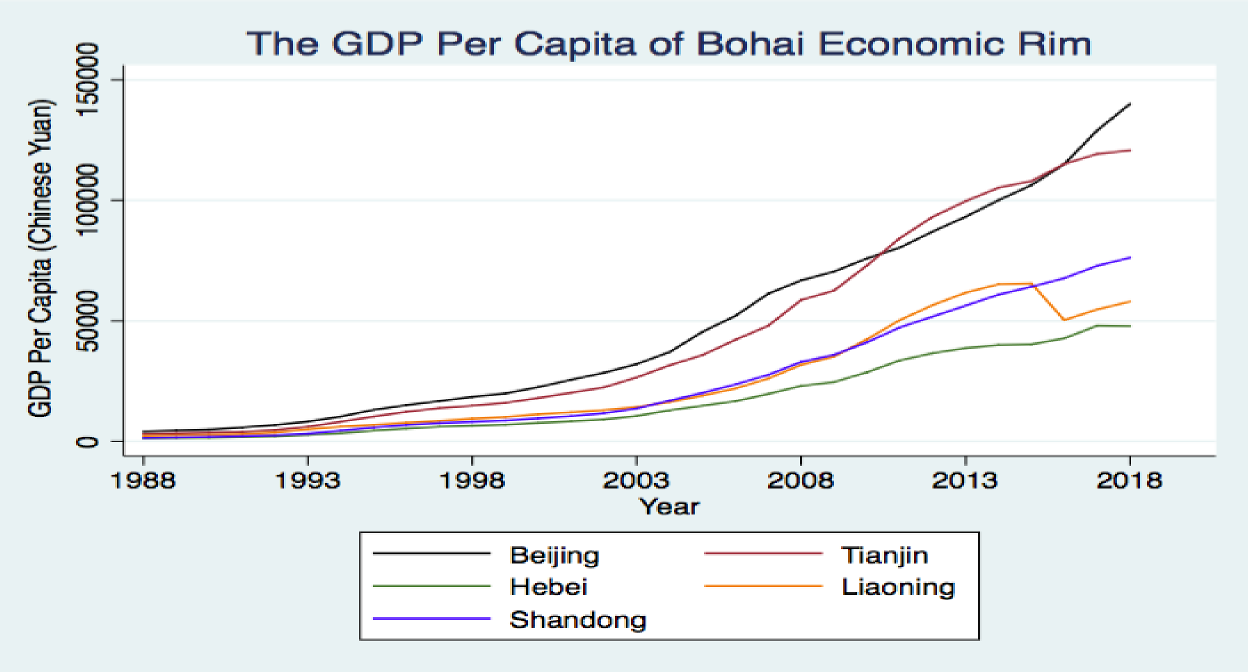

Figure 2: The GDP Per Capita of Bohai Economic Rim

Along with the economic growth of these areas, the volume of the industrial and domestic wastewater has also been increased significantly. In 2003, the total amount of industry wastewater in China was over 21,000 million tons, and the household sewage was 24,700 million tons. The industrial sewage of the Shandong Province accounted for approximately 42% of the total wastewater in these five locations or areas from 2003 to 2017. Furthermore, the domestic wastewater contributed just over 34% in selected locations. In Beijing, the household wastewater consists of approximately 18% of the wastewater. However, Beijing makes up a lower percentage in industrial sewage: 2.4% [2]. Based on the EKC hypothesis, the current study will examine the relationship between wastewater and GDP in each of these areas.

4 Data

The data used in this paper is the annual data set during the period from 2003 to 2017. The data are gathered from *China Statistical Yearbook* from 2003 to 2019,[3] focusing on the major northern places that we studied, including areas of Beijing, Tianjin, Hebei Province, Shandong Province and Liaoning Province. Moreover, the industrial wastewater discharge (denoted as Y_1) and household domestic sewage (denoted as Y_2) play important roles in the environmental pollution around the Circum-Bohai-Sea Zone. I use x to represent the per capita GDP, which measures the income level and economic development.

To examine the relationship between the total volume of sewage emission and the income level, I assign the variable Y_3 to be the total wastewater discharge. Thus, I construct three models: (1) the volume of industrial wastewater discharged and per capita GDP, (2) the volume of domestic sewage and per capita GDP, and (3) the total volume of wastewater discharged and per capita GDP.

The traditional EKC hypothesis highlights that the role of improving technological progress can change the measurement of environmental quality and create a sustainable economic growth pathway to some degree. Higher income and higher education can increase the probability of raising public concern and creating efficient water treatment technologies and regulation. Therefore, the current study will use the number of universities to be a proxy of technologies to determine whether their EKC curves will be flatter

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[2] See the Pie Chart was created in Appendix A. *The Percentage of Industrial Wastewater Discharge of Each Subregion*

[3] The data source is from National Bureau of Statistics, China

across the different subregions being studied.

5 Environmental Kuznets Curve Model

5.1 The Model

In this part, we provide a simple theory for the conventional EKC. The traditional models emphasize scale economy, technology, and regulation from the production perspective as influencing factors in the determination of the environmental Kuznets curve (Grossman & Krueger, 1991; Van Lantz, 2000). The following model focuses on the consumption or demand side of the economy in determining the relationship between pollution and the output of the economy.

In this model, we assume that $c_0 > 0$ represents the subsistence consumption, $e_0 > 0$ represents the level of environment quality at which the economy makes little effort to reduce the pollution, y is the economy's GDP level, and $\bar{X}$ is the capacity of the economy in a given period. We also assume that $\bar{X} > c_0$ and that the economy has the following objective function:

$$U(c, e) = \alpha(c - c_0)^{\frac{1}{\rho}} + \beta(e - e_0)^{\frac{1}{\rho}}, \tag{1}$$

where c is the consumption level, e is the environment quality level.

We assume that there is a trade-off between the environment quality e and the GDP y of the economy. The following relation represents this trade-off or the strain between the GDP and the environment:

$$c + ey \leq \bar{X}.$$

If the economy maximizes its objective function subject to the above capacity constraint, then the following formula can be applied:

$$\begin{aligned} \max U(c,e) &= \alpha(c-c_0)^{\frac{1}{\rho}} + \beta(e-e_0)^{\frac{1}{\rho}} \\ \text{s.t.} \qquad & c + ey \leq \bar{X}. \end{aligned} \tag{2}$$

For the sake of simplicity, the following assumes that $\alpha = \beta = 1$ and $\rho = 2$. The first step derives the environment quality as a function of the economy's GDP,

$$e = e(y).$$

The Lagrangian of the problem (2) is

$$L = (c-c_0)^{1/2} + (e-e_0)^{1/2} + \lambda(\bar{X} - c - ey).$$

Upon solving the first order conditions of the Lagrangian, we obtain

$$e = \frac{\bar{X} - c_0 + e_0 y^2}{y^2 + y}.$$

Thus,

$$\frac{de}{dy} = \frac{e_0 y^2 - 2(\bar{X} - c_0)y - (\bar{X} - c_0)}{(y^2+y)^2}.$$

It is easy to show that

$$\frac{de}{dy} < 0, \text{ if } 0 < y < \frac{(\bar{X} - c_0)(1 + \sqrt{1+e_0})}{e_0},$$

and

$$\frac{de}{dy} > 0, \text{ if } y > \frac{(\bar{X} - c_0)(1 + \sqrt{1+e_0})}{e_0}.$$

This implies that the lack of the environment quality, considered as the opposite of the environment quality expressed as $-e(y)$, exhibits the following property:

$$-\frac{de}{dy} > 0, \text{ if } 0 < y < \frac{(\bar{X} - c_0)(1 + \sqrt{1 + e_0})}{e_0},$$

and

$$-\frac{de}{dy} < 0, \text{ if } y > \frac{(\bar{X} - c_0)(1 + \sqrt{1 + e_0})}{e_0}.$$

This shows that the economy's environment Kuznets curve is an inverted U curve.

Theorem 1 *The economy's environment Kuznets curve is an inverted U curve and its peak decreases as either* c_0 *increases or* e_0 *increases or both.*

The proof of the theorem is obvious and omitted.

5.2 The Different Forms of EKC

In general, the basic econometric model could be the linear, quadratic, or cubic equation, and the sign of the coefficient parameters can demonstrate the types of patterns. To identify the regression between water pollution and the income level, the current study will use the following formula:

$$Y_1 = \alpha_0 + \alpha_1 x + \alpha_2 x^2 + \alpha_3 x^3 + e_1 \tag{3}$$

Conforming to the implication of coefficient parameters, the summarized Table 1 is listed below in an attempt to use both the fixed and random-effects models on equation (3). Under the assumption that α_1 is greater 0, and $\alpha_2 = \alpha_3 = 0$, then this demonstrates that there is a linear monotonic increase. Thus, the water quality gets progressively worse as the per capita GDP increases. Additionally, if α_1 >0, α_2 <0, and $\alpha_3 = 0$, then the inverted U-shaped relationship appears; therefore, the water quality of production declines when the per capita GDP rises after the turning point. This is consistent with the classical EKC model. Moreover, the N-type curve appears for α_1 >0, α_2 <0 and α_3 >0. Along with the gradually income levels rising, the wastewater originally had a classical EKC model and then rose to another inflection point to and continues to rise.

Table 1: The Different Forms of EKC

Cases	**Value of α_i**	**Forms of the curve**
Case 1	α_1>0, α_2=α_3=0	Linear monotonic increase
Case 2	α_1>0, α_2<0, α_3=0	Inverted U-shaped relationship
Case 3	α_1>0, α_2<0, α_3>0	N-type relationship

In this context, it is important to recognize that the classical EKC is a negative parabola; thus, on the application of EKC hypothesis, the current study will establish the quadratic form of equations to find the turning point and illustrate the trend in water pollution:

$$Y_1 = \beta_0 + \beta_1 x + \beta_2 x^2 + e_1 \tag{4}$$

$$Y_2 = \beta_3 + \beta_4 x + \beta_5 x^2 + e_2 \tag{5}$$

$$Y_3 = \beta_6 + \beta_7 x + \beta_8 x^2 + e_3 \tag{6}$$

where Y_1 is the industrial wastewater discharge, Y_2 is the urban domestic sewage, Y_3 is the total wastewater discharge, and x is the per capita GDP. The β_0, β_3 and β_6 are parameters of regressions.

5.3 Model 1

First, the analysis of Model 1 shows the sign of x^2 is negative in equation (4), which means the turning point will appear in Model 1. To maximize the first order condition of this equation, the turning point is 41,869.64 RMB. Hence, the industrial wastewater pollution will decrease after the income level reaches approximately 43,692 RMB. This is demonstrated in the following equation:

$$\hat{Y_1} = 359909.5 + 2.455481x - 0.0000281x^2 \tag{7}$$

$$\begin{aligned} x &= \frac{b_1}{2b_2} \\ x &= \frac{2.455481}{2 \times 0.0000281} \\ x &= 43692 \end{aligned}$$

The per capita GDP represents the income level, which clearly demonstrates that the income level is in the lower stages before the point of inflection. When the income level is in the high stage, the water quality improves if incomes rise. This is consistent with the rise and fall of EKC theory. However, the estimation results in Table 2 below, which indicates that the model does not fit well given that the R^2 is low and the P-value of x^2 is greater than 10%. Therefore, Model 1 does not satisfy the EKC model.

Table 2: The Quadratic Form of the Industrial Wastewater Discharge

Variables	Coefficient Estimates	Standard Errors	P-values
constant	359909.5	20119.77	0.000***
x	2.455481	1.368992	0.098*
x^2	-0.0000281	0.0000199	0.184
SSE	2.9522e+09		
R^2	0.3526		
AdjustR^2	0.2447		
Prob>F	0.0736		
DW	1.185679		

Note: Significant levels: *:10%; **:5%; ***1%.

Therefore, applying the cubic equation will help determine the relationship between industrial sewage emission and national income level. The cubic equation and estimation results are shown in Table 3 below. After improving the equation (4), it is clear that the R^2 is higher than before. The value of R^2 is 0.5459; thus, it demonstrates that 54.59% of the variance in industrial wastewater discharged around its mean. Moreover, the P-values of each variable are less than 10%, which indicates that the coefficient of each independent variable is statistically significant. The probability of F test is 0.0288, which is less than before; hence, approximately 3% of the regression parameters are zero, implying the overall model is more valid in fitting the data than before.

When recalling the cubic equation (3), the equation becomes:

$$\hat{Y_1} = 282689.3 + 11.48903x - 0.0003225x^2 + 0.00000000283x^3 + e_1 \tag{8}$$

Table 3: The Cubic Form of the Industrial Wastewater Discharge

Variables	Coefficient Estimates	Standard Errors	P-values
constant	282689.3	39793.53	0.000***
x	11.48903	4.343492	0.023**
x^2	-0.0003225	0.0001372	0.038**
x^3	2.83e-09	1.31e-09	0.053*
SSE	2.0709e+09		
R^2	0.5459		
AdjustR^2	0.4220		
Prob>F	0.0288 ***		
DW	1.536242		

Note: Significant levels: *:10%; **:5%; ***1%.

Although the R^2 is not high enough, each indicator is statistically significant. The adjusted R^2 is higher than before, and this means adding additional predictors improves a regression model. The pattern is an N-type curve, which means it will be an increasing trend in the near future if the standard of industrial sewage discharge is not be strictly controlled. The N-type curve is not good because it does not satisfy the classical EKC model. However, the coefficient of x^3 is very low, so it is better to implement the environmental policy to protect the environment as matters stand. The current study researched the past 15 years of data; however, if there are larger improved further data sets, the pattern will likely change with expectation to form EKC model. The problem of "spurious regression" results in a low value for the Durbin-Watson (DW) statistic, which is lower than the R-squared. However, both the regression for quadratic and cubic show they have higher DW value than R-squared. Thus, they are not spurious regression case.

Comparing the two equations (7) and (8) of Model 1, the former one explains the EKC pattern, but the model is not applicable by testing. The latter equation is moderately relative to a N-typed shaped. Owing to the smaller value of the cubic regressor, the further improvement can control pollution to improve the model.

5.4 Model 2

The Model 2 illustrates the "volume of household wastewater discharged and GDP per person". Y_2 is another vital indicator to form the sewage discharged. By analyzing the sign and magnitude of each variable, the change of the squared of per capita GDP to individual wastewater is -0.0001632, which is less than the change of the squared of per capita GDP to industrial polluted water. The constant number of household wastewater is lower than the industrial sewage discharged. Thus, the industry wastewater can cause more pollution.

$$\hat{Y_2} = 196319.3 + 20.84933x - 0.0001632x^2 \tag{9}$$

Throughout the results and parameters of regression in Table 4 below, it can be seen that the R^2 is 0.9782, or 97.82% of the variation in the individual wastewater. The R^2 is close to 100%, which means it appears to be a suitable model. To be precise, the value of DW test is around 1.8, which is higher than R^2. The adjusted R^2 is 0.9746, and the probability of F test is 0.0000; hence, the model is valid. The coefficients of each independent variables are statistically significant by testing the P-value, which is less than 0.01. The parameter of β_4 is positive, and β_5 is negative; consequently, the shape of graph is inverted-U. This demonstrates the EKC hypothesis. The turning point is 63876.62 RMB; thus, after the income level of 63876.62 RMB, the domestic sewage discharge will fall.

Table 4: The Quadratic Form of the Household Wastewater Discharge

Variables	Coefficient Estimates	Standard Errors	P-values
constant	196319.3	33250.53	0.000***
x	20.84933	2.262436	0.000***
x^2	-0.0001632	0.0000329	0.000***
SSE	8.0631e+09		
R^2	0.9782		
AdjustR^2	0.9746		
Prob>F	0.0000***		
DW	1.795967		

Note: Significant levels: *:10%; **:5%; ***1%.

5.5 Model 3

Finally, the analysis of Model 3 and estimation results, seen in Table 5, demonstrate that the R^2 is 0.9758, which also indicates it is nearly a suitable model. R^2's 97.58% variation of the total wastewater is explained by per capita GDP in the regression. The higher adjusted R^2 and lower DW value supporting it appears an ideal model. According to the P-value of each variable, it is noticeable that the coefficients are significant at the level of 10%. The coefficient of x^2 in Model 3 is the smaller value than the equation (4) and (6). The turning point is 60911.68 RMB. Thus, after the income level reaches 60911.68 Chinese Yuan, the total wastewater will decline. The pattern will be a negative parabolic shape.

$$\hat{Y_3} = 556228.8 + 23.30481x - 0.0001913x^2 \tag{10}$$

Table 5: The Quadratic Form of the Total Wastewater Discharge

Variables	Coefficient Estimates	Standard Errors	P-values
constant	556228.8	37231.17	0.000***
x	23.30481	2.533288	0.000***
x^2	-0.0001913	0.0000369	0.000***
SSE	1.0109e+10		
R^2	0.9759		
AdjustR^2	0.9719		
Prob>F	0.0000***		
DW	1.684997		

Note: Significant levels: *:10%; **:5%; ***1%.

To sum up, based on the equations, the industrial wastewater emission has a N-typed pattern. It is a signal of increasing trend; therefore, it is important to promote policies that effectively manage industrial emission to protect the water resource around Bohai Sea. The situation of the domestic personal sewage is better now because it has a downward trend. Nevertheless, the coefficient of the squared of per capital GDP is relatively small; thus, it is critical to not only maintain the current status but also decrease the discharge of sewage. The total amount of wastewater is the sum of industrial and household sewage. As a result, it is better to decrease the water pollution by reducing the industrial and domestic wastewater discharge.

6 Graphical Analysis

The current study also applied STATA software to simulate the relation between the water pollution and the economic development (see results in Fig. 3-6). Compare the equation (7) with (8), the pattern is a N-typed shape since the formula (8) is fitting better.

However, the chart in Fig.3 illustrates a typically inverted U-Shaped quadratic curve when simulating the relationship between industrial water pollution and the economic development. The turning point is consistent with the equation (7). However, when examining the scatter diagram in Fig.4, it is clear that the pollution fluctuates with economic development. After the per capital GDP around the 40000 Chinese Yuan, the pollution increase. Therefore, it confirmed the current study's conclusions namely that there should be a focus on water resources and efforts should be made to decrease the industrial wastewater discharge in the near future. The purpose is to decrease the water pollution associated with economic development.

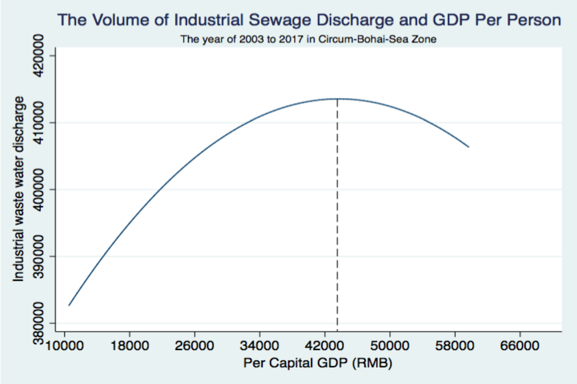

Figure 3: Industrial Wastewater Discharge

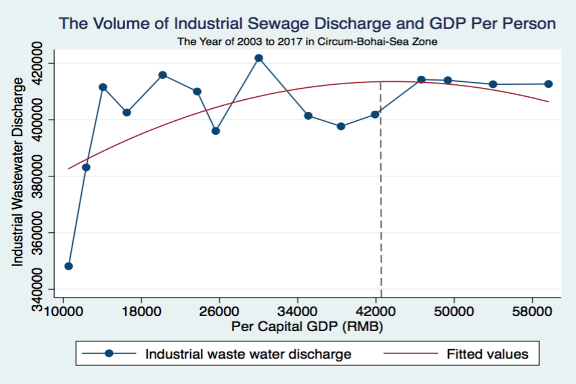

Figure 4: Industrial Wastewater Discharge with Scatter Diagram

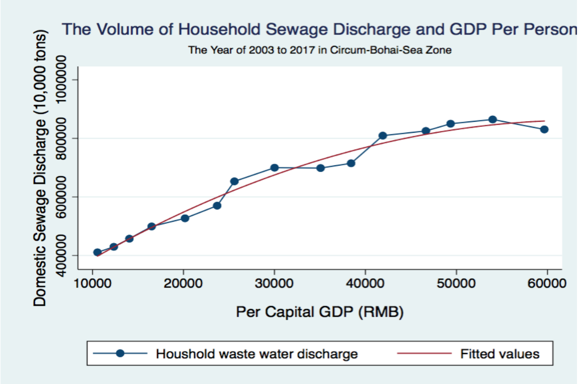

Figure 5: Household Sewage Discharge

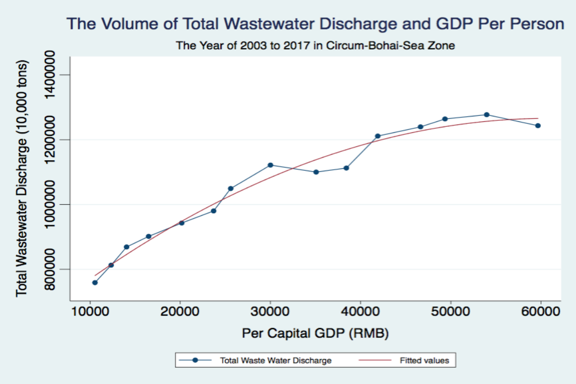

Figure 6: Total Wastewater Discharge

To establish a clear picture of the EKC graphs regarding the household and total wastewater discharge related to economic growth, the diagrams in Fig. 5-6 illustrate how their respective turning points recently appeared. Combined with their scatter diagrams, they imply that the turning points of less pollutants appeared recently. An analysis of the EKC model suggests that policies can help preserve the status of water resources and help prevent from regressing. This is because a regression in water quality will lead to a turning point is difficult to come back from; thus, the EKC model would become a flimsy statistical application to evaluate the relation between environment and income level. Therefore, there is a list of strategies and regulations that are made for the environment and can secure efficient consequences.

7 Comparative study across different subregions

As shown empirically, the environment Kuznets curve demonstrates that, as an economy's GDP increases after its GDP reaches certain level, the environment will improve as its GDP continues to increase. It has also been shown empirically that, as an economy's technology advances, its environmental Kuznets curves will shift downward. This indicates that the maximum of pollution will reach a lower point than before in a long run.

These empirical findings may cause governments to treat the economy's environment Kuznets curve as a policy tool, arguing for a 'develop first, clean after' policy. However, as demonstrate by the 'Lucas Critique,' when the rules of the game change, people's behavior also changes. Thus, it might be that the historical relationship between pollution and the GDP of an economy expressed in a Kuznets curve may not hold (e.g., N-shaped curve. See Grossman and Krueger, 1995).

Therefore, the current paper evaluates the effect of technologies on EKC model of each subregion to determine if some have flatter curves due to technological progress.

The variable of universities is used as a proxy of technologies to compare their impact on the EKC model.

The original model is (E1):

$$TW_{it} = \gamma_0 + \gamma_1 PGDP + \gamma_2 PGDP^2 + e_1 \tag{11}$$

The model with technologies is (E2):

$$TW_{it} = \gamma_0 + \gamma_1 PGDP + \gamma_2 PGDP^2 + \gamma_3 universities_{it} + e_2 \tag{12}$$

Where i denotes each subregion separately (i.e. Beijing, Tianjin, Hebei Province, Shandong Province, Liaoning Province, separately), and t is the time. Likewise, TW_{it} denotes the total wastewater of each subregion, $PGDP$ is the per capita GDP, an $universities_{it}$ is the number of universities for each subregion.

Table 6: The Effect of Technologies on EKC Model

Equation	Subregions	Turning point
E1	Beijing	51023.04
E2	Beijing*	49157.16
E1	Tianjin	174088.2
E2	Tianjin*	75207.26
E1	Hebei Province	45968.82
E2	Hebei Province*	44791.7
E1	Liaoning Province	No Turning Point
E2	Liaoning Province*	112890.26
E1	Shandong Province	58850.184
E2	Shandong Province*	59216.54

Note: * is the new point of each subregion in E2.

A comparison of the turning point of subregions was used to determine the effect of technologies to total sewage discharged and economics, and this demonstrates that the turning point is lower than before (equation 1), with the only exception of Shandong Province. For example, the turning point of Hebei Province with the variable of universities is approximately 1000 RMB lower than without the indicator universities. Meanwhile, the Kuznets curve will shift left because the pollution will decrease and reach a lower point between water pollution and economic development (Figure 7). In contrast, the turning point of Shandong Province with technologies will increase by approximately 1000 RMB. Hence, the number of universities in Shandong will create higher levels of water pollution and shift the point of EKC curve to the right (Figure 8).

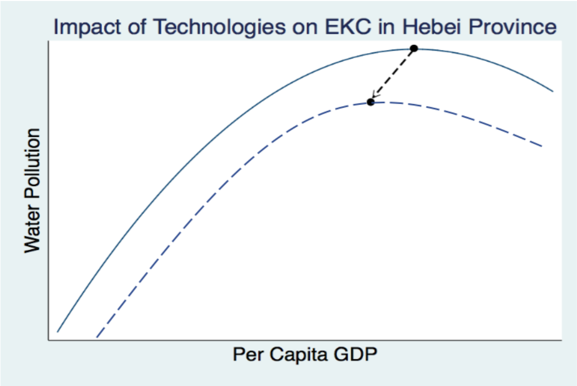

Figure 7: The Technologies Effect of EKC in Hebei Province

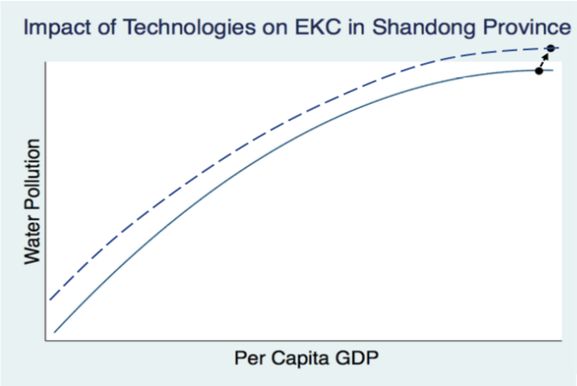

Figure 8: The Technologies Effect of Shandong Province

8 Conclusion

On the basis of the theory of the EKC hypothesis, this paper studies the relationship between water pollution and the economic growth in the Bohai Sea region in northern China. The current study collected 15 years of data to analyze economic growth and water environmental degradation around the Circum-Bohai-Sea Zone. The results demonstrate that the relationship between economic growth and industrial water degradation has an inverse U-shaped feature, which is generally consistent with the typical shape of the EKC. However, the estimation results also identified some discrepancies from the standard model when technologies are considered. These results indicate that water pollution would get worse if the government does not push more interventions to water management. The econometric model of domestic sewage and total wastewater are well suited, and each variable is significant, and the turning points exist as shown by the classical EKC model. The comparative study illustrates that, when an economy's technology advances, the EKC shift is downward in each subregion, except Shandong Province.

Water has been seriously deteriorated in the Bohai Economic Rim. Using the EKC model as a policy tool, the current study demonstrates that the conflict between environmental pollution and economic growth can be mitigated by actively promoting environmentally friendly technology advancement in water resource management.

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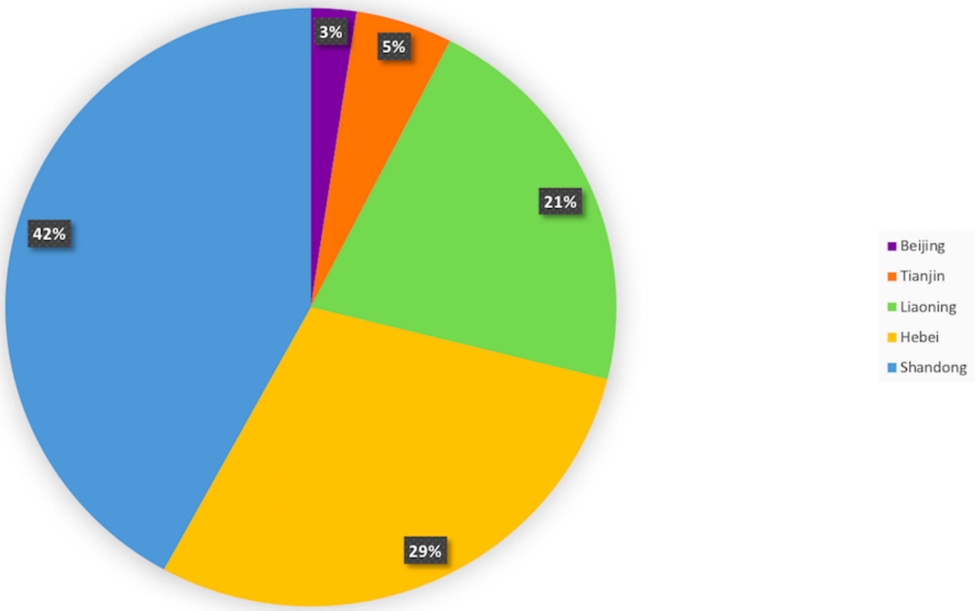
Appendix

Appendix A.

The Percentage of Industrial Wastewater Discharge of Each Subregion



Data Source : National Bureau of Statistics of China (2018). *China Statistical Yearbook (2003-2018).* China Statistics Press.

Appendix B.

Table 7: Econometric Results about Each Subregion

	E1	**E2**	**E1**	**E2**	**E1**	**E2**
Variable	Beijing	Beijing*	Tianjin	Tianjin*	Hebei Province	Hebei Province*
constant	59669.06	-39552.52	36754.76	55246.46	141731.3	120449.9
P-value	0.000***	0.769	0.000***	0.004***	0.000***	0.003***
PGDP	3.408339	2.005612	1.176836	2.1659699	5.47029	4.712087
P-value	0.001***	0.345	0.014**	0.027**	0.000***	0.003***
$PGDP^2$	-0.0000334	-0.0000204	-3.38e-06	-0.0000144	-0.0000595	-0.0000526
P-value	0.017**	0.351	0.580	0.184	0.000***	0.002***
$universities_{it}$		1505.672		-711.6821		350.1271
P-value		0.464		0.215		0.512
Turning Point	51023.04	49157.16	174088.17	75207.26	45968.824	44791.7
Prob>F	0.0000***	0.0001***	0.0000***	0.0000***	0.0000***	0.0000***
R^2	0.8362	0.8443	0.9247	0.9350	0.9541	0.9559
$adjR^2$	0.8089	0.8019	0.9122	0.9172	0.9464	0.9439
DW test	2.022763	2.19402	1.974892	2.390073	1.601097	1.544864

Note: Significant levels: *:10%; **:5%; ***1%.

Continuous

	E1	**E2**	**E1**	**E2**
Variable	Liaoning Province	Liaoning Province*	Shandong Province	Shandong Province*
constant	195577	219675.8	122484	114342.3
P-value	0.000***	0.000***	0.000***	0.280
PGDP	0.4564435	3.025459	12.79403	12.31704
P-value	0.631	0.219	0.000***	0.063
$PGDP^2$	-0.0000137	-0.0000134	-0.0001087	-0.000104
P-value	0.331	0.617	0.001***	0.118
$universities_{it}$		-720.2195		139.9859
P-value		0.254		0.935
Turning Point	No Turning Point	112890.2612	58850.18399	59216.54
Prob>F	0.0000***	0.0001***	0.0000***	0.0000***
R^2	0.8363	0.8553	0.9660	0.9660
$adjR^2$	0.8090	0.8159	0.9603	0.9567
DW test	1.178341	1.284286	2.117367	2.116831

Note: Significant levels: *:10%; **:5%; ***1%.

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