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The Empirical Study Between Economic Growth and Environmental Pollution in China's Municipalities

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Abstract

In order to explore the quantitative relationship between economic growth and environmental pollution, the paper takes China's 4 municipalities, namely, Beijing, Tianjin, Shanghai and Chongqing, as the target for research. In terms of indexes selection, we choose GDP per capita from 1997 to 2012 as the economic development indicator. On the other hand, we select discharge of industrial waste water, emission of industrial waste gas, emission of industrial sulfur dioxide and discharge of industrial solid waste as the environmental pollution indicators. And by means of the typical Environmental Kuznets Curve, we build the cubic polynomial function model between GDP per Capita and the four environmental pollution indicators. Furthermore, the empirical results turn out that the relationship between economic growth and environmental pollution is abundant in N and inverted N shape, which means that inverted U shape(the typical EKC) is just one form of them. Finally, in view of the harmonious development between economy and environment, we put forward some effective suggestions.

Key words: The EKC; Economic growth; Environmental pollution

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INTRODUCTION

In order to further promote the development of Chinese characteristic socialism, in 2012, the 18th report of the Communist Party of China[1] made the overall layout of construction in five aspects. For the first time, Chinese government put ecological civilization construction on an equally important position with economic construction, political construction, cultural construction and social construction, aiming at building a prosperous society in an all-round way, realizing socialist modernization and rejuvenating the great Chinese nation. With the rapid development of social economy, the attendant environmental pollution is becoming more and more serious, and it has aroused great concern from all sectors of society.[2] Against such background, studying the quantitative relationship between economic growth and environmental pollution is of great importance.

1. LITERATURE REVIEW ON THE EKC

The Environmental Kuznets Curve (EKC) was initially a doctrine, with which the American economist Kuznets analyzed the relationship between the level of income per capita and the degree of distribution justice in the 1950s. His research suggested that income inequality firstly expanded and then narrowed with the economic development, presenting an inverted U shape relationship (Kuznets, 1955), as shown in Figure 1.

In the 1990s, American economists e.g. Grossman, through the analysis of 42 countries' cross section data, drew the conclusion that there was an inverted U shape relationship between many of the pollutants and GDP per capita. Namely, in the early stage of industrialization,

[1] The 18th national congress of the communist party of China was held on November 8th in 2012.

[2] The economic analysis on the environmental pollution can trace back to 1932, aiming at the environmental pollution in London, Pigou thought that it was the external problems that caused the environmental pollution. However, it is until 1960s that sociologists and economists generally realize that environmental pollution is a big threat to humans. (Fisher & Peterson, 1976, p.3)

environmental quality will deteriorate with the development of economy; when the economic level reaches certain degree, the environment will gradually improve, i.e. the typical EKC (Grossman & Krueger, 1991). As shown in Figure 2.

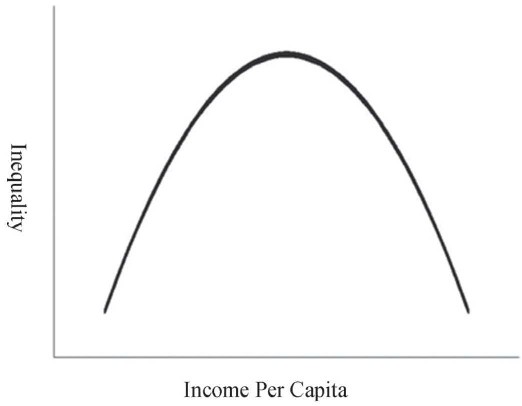

Figure 1
The Kuznets Curve

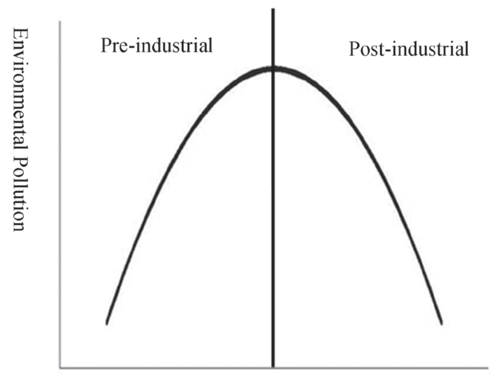

Figure 2
The Environmental Kuznets Curve

Since the EKC (Environmental Kuznets Curve) was proposed by Grossman and krueger in 1991, it has attracted much attention of numerous scholars from all over the world. Some scholars confirmed the existence of the EKC. Shafik & Bandyopadhyay (1992) found that emissions of sulfur dioxide (SO_2) and suspended particulate matter (SPM) originally raised and then reduced with the increase of income per capita. Panayotou (1993) found that the relationship between the degree of forest deforestation and income per capita was shown in an inverted U shape curve. Selden & Song (1994) conducted the study on four air indexes, i.e. SO_2, Nitric oxide (NO_x), Cobalt (CO) and SPM and confirmed the existence of EKC. Panayotou (2003) discovered that there was an inverted U shape relationship between carbon dioxide (CO_2) and economic growth. Chinese academic Wu Yuping (2002) found that there was an inverted U shape relationship between economic growth and environmental pollution in Beijing. The study on Wenzhou, Zhejiang province indicated that except emission of industrial waste gas, other industrial environmental pollutants and GDP per capita were obviously in line with the typical EKC (Wang, & Li, 2005). Guo and Li (2010) found that discharge of industrial solid waste and GDP per capita met with the EKC, using 29 provinces' panel data from 1991 to 2007 in China.

However, some others did not support the EKC hypothesis. Kaufmann et al. (1998) found that the trend of income per capita and sulfur dioxide (SO_2) were U shape, other than inverted U shape. Chinese Liu (2007) did research on Yantai, Shandong province, using three environmental pollution indexes and GDP per capita, and the results reflected that the inverted U shape was not the general rule. Zhou, Yuan, Xue and Zhou (2009) made the study on Shanxi Province, finding that there was a long-run equilibrium relationship between economic growth and discharge of industrial waste water, showing the N shape curve. Ding (2012) conducted the study on Guangxi province and came to the results that there was a statistically significant N shape instead of an inverted U shape relationship between environmental pollution and economic growth. Wang (2013) conducted the research and found that the trend between costal area economy and marine environmental pollution was presented as a N shape curve.

Above all, it can be seen that there does exist certain EKC relationship between environmental pollution and economic growth, but it may be inverted U shape, i.e. the typical EKC, may be N shape, inverted N shape or other similar shapes. In the paper, we attempt to explore the evolution rules between economic growth and environmental pollution in China's four municipalities. In the end, we will provide some helpful suggestions for promoting common development of environment and economy.

2. EMPIRICAL STUDY BASED ON THE EKC

On the basis of the typical EKC model, we conduct the empirical study between economic growth and environmental pollution in Beijing, Tianjin, Shanghai and Chongqing.

2.1 Index Selection

In 1997 Chongqing was carved out of Sichuan province into a municipality that reports directly to Beijing. In order to fully study the succession rule between economic growth and environmental pollution, the time for research ranges from 1997 to 2012. In addition, the main inducement that evokes environmental quality deterioration is discharges of industrial "three wastes". So we choose discharge of industrial waste water, emissions of industrial waste gas and industrial sulfur dioxide (SO_2) and discharge of industrial solid waste as environmental pollution indicators. On the other hand, we choose GDP per capita[3] as economic development indicator. The basic data are shown in Appendix A to Appendix D. Furthermore, we draw figures with Origin software, as shown in Figure 3 to Figure 7.

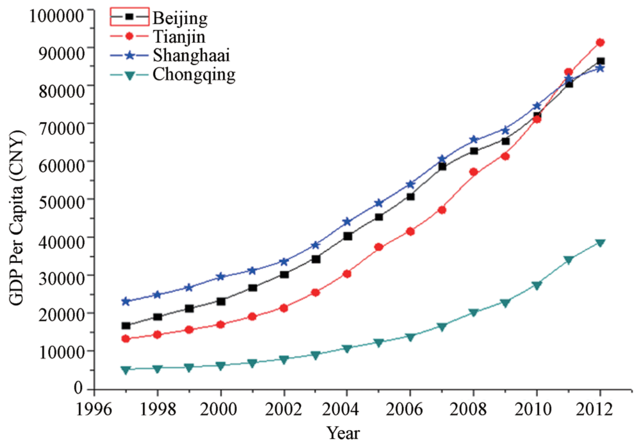

Figure 3
The Trend of GDP Per Capita

Figure 3 vividly depicts the trend of GDP per capita from 1997 to 2012 in Beijing, Tianjin, Shanghai and Chongqing. Although the change of GDP per capita in China's four municipalities is different, the overall trend is all upward. Averagely speaking, GDP per capita of China's four municipalities, adjusted for inflation, has almost sextupled since 1997.

Moreover, from the total economy point of view, Shanghai has occupied the first place unchallenged since 1997; Beijing and Tianjin followed after Shanghai, respectively ranking the second and the third. However, from the perspective of GDP per capita, Tianjin exceeded Shanghai and Beijing in 2011 and has been in the first place till now. On the whole, Shanghai and Beijing's economy performed better than that of Tianjin in the past 16 years.

In addition, economic development level varies greatly among the four municipalities. Chongqing's economy has expanded greatly since she became the municipality city. But compared with the other three municipalities, Chongqing still lags behind and the absolute amount of gap is likely to widen, just as shown in Figure 3. The evidence that GDP per capita of Shanghai was 4 times that of Chongqing in 1997, which became 2.18 times in 2012, shows that those stubborn gaps have begun to close.

Based on the panel data of China's four municipalities, we draw figures below to present the tendency of the four environmental pollution indicators from 1997 to 2012, as shown in Figure 4 to Figure 7.

[3] GDP Per Capita of China's four municipalities is calculated by resident population of Beijing, Tianjin, Shanghai and Chongqing.

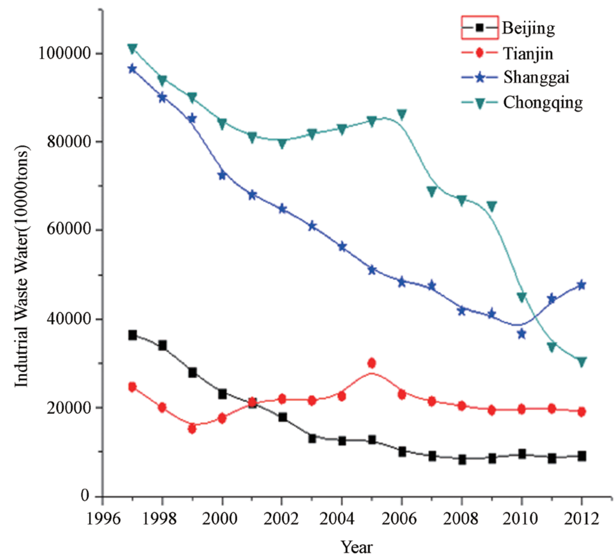

Figure 4
The Trend of Industrial Waste Water

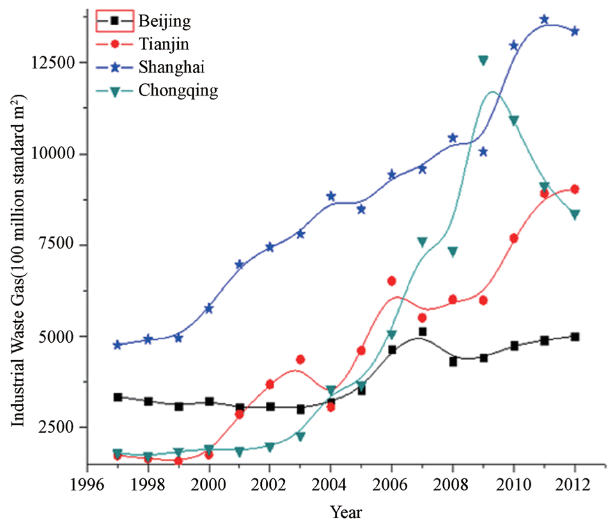

Figure 5
The Trend of Industrial Waste Gas

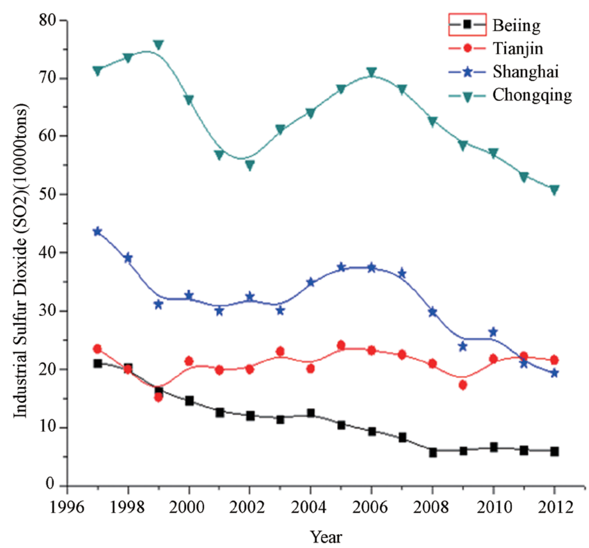

Figure 6
The Trend of Industrial SO_2

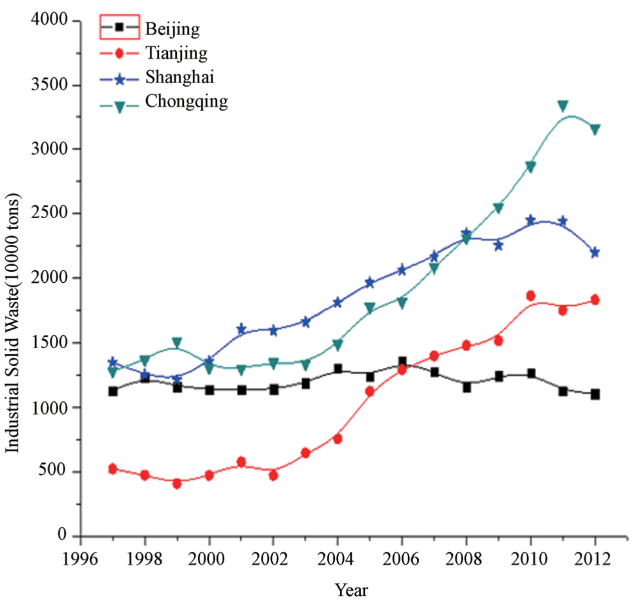

Figure 7
The Trend of Industrial Solid Waste

Figure 4 and Figure 6 have the same trend: in the last 16 years, discharge of industrial waste water and emission of industrial sulfur dioxide (SO_2) were decreased on the whole. The absolute volume ranking followed by Chongqing, Shanghai, Tianjin and Beijing.

The tendency of emission of industrial waste gas (as shown in Figure 5) was on the rise as a whole from 1997 to 2012. Chongqing had the largest increase in it, followed by Shanghai, Tianjin and Beijing. But the absolute volume ranking followed by Shanghai, Chongqing, Tianjin and Beijing.

Figure 7 has a similar tendency with Figure 5, the difference is that: discharge of Industrial solid waste in Chongqing, Shanghai and Beijing started at a similar point in 1997, but they moved into different directions after 16 years' development. Beijing showed a downward trend in the fluctuation, while Shanghai and Chongqing just the opposite. Tianjin presented a trend of increasing between 1997 and 2012.

In conclusion, we calculate the mean value for various indicators in China's four municipalities and draw a table (as shown in Table 1) combining with the analysis above.

Table 1
The Mean Value and the Ranking for Various Indicators

Municipality	GDP per capita (CNY)	Industrial waste water (10000 tons)	Industrial waste gas (100 million standard m^3)	Industrial SO_2 (10000 tons)	Industrial solid waste (10000 tons)
BJ	45871.366	16467.81	3867.94	11.2175	1199.7531
TJ	40424.985	21125.50	4680.6875	21.0369	1035.3500
SH	49306.489	59608.81	8714.00	31.6119	1857.5194
CQ	15282.150	73675.69	5100.3987	63.4640	1928.5994
Ranking	SH > BJ > TJ >CQ	CQ>SH>TJ >BJ	SH>CQ>TJ>BJ	CQ>SH>TJ>BJ	CQ>SH>BJ>TJ

2.2 Model Building

In general, the inverted U shape EKC usually has three kinds of basic functions: quadratic function, cubic function and mixed function. Since cubic polynomial function has the advantages of high goodness of fit and high precision of *F* test, we build cubic function as Equation (1)[4]:

$$Y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \varepsilon \qquad (1)$$

X on behalf of GDP per capita, the unit is CNY.

Y on behalf of various environmental pollution indicators, including discharge of industrial waste water, emission of industrial waste gas, emission of industrial sulfur dioxide (SO_2) and discharge of industrial solid waste, the units respectively are 10,000 tons, 100 million standard cubic meters, 10,000 tons and 10,000 tons.

$\overset{\circ}{a}$ on behalf of random error.

$\hat{a}_0, \hat{a}_1, \hat{a}_2, \hat{a}_3$ on behalf of the regression coefficients. When they are taken different values, the relationship between economic growth and environmental pollution is as follows:

1) $\hat{a}_1 = \hat{a}_2 = \hat{a}_3 = 0$, a straight line, i.e. economic growth has no effect on environment.

2) $\hat{a}_1 > 0, \hat{a}_2 = \hat{a}_3 = 0$, monotone increasing, i.e. environment deteriorates with economic growth.

3) $\hat{a}_1 < 0, \hat{a}_2 = \hat{a}_3 = 0$, monotone decreasing, i.e. environment improves with economic growth.

4) $\hat{a}_1 > 0, \hat{a}_2 < 0, \hat{a}_3 = 0$, inverted U shape, i.e. the typical EKC, environment deteriorates before improves with economic growth.

5) $\hat{a}_1 < 0, \hat{a}_2 < 0, \hat{a}_3 = 0$, U shape relationship, i.e. environment improves before deteriorates with economic growth.

[4] The relationship between economic growth and environmental pollution varies with the different beta coefficients. Many scholars have found that the scope of application of the typical inverted U is limited. The paper chooses the cubic polynomial function model so that we can fully study the relationship between economy and environment.

6) $\hat{a}_1 > 0, \hat{a}_2 > 0, \hat{a}_3 > 0$, N shape relationship, i.e. environment deteriorates, then gradually improves and finally deteriorates with economic growth.

7) $\hat{a}_1 < 0, \hat{a}_2 > 0, \hat{a}_3 < 0$, inverted N shape relationship, i.e. environment first improves, then gradually deteriorates and finally improves with economic growth.

3. THE ANALYSIS FOR EMPIRICAL RESULTS

3.1 Preliminary Judgment by Graphics

We first draw the double Y figures for each municipality using Origin software, making a preliminary judgment about the EKC shape, as shown in Figure 8 to Figure 11.

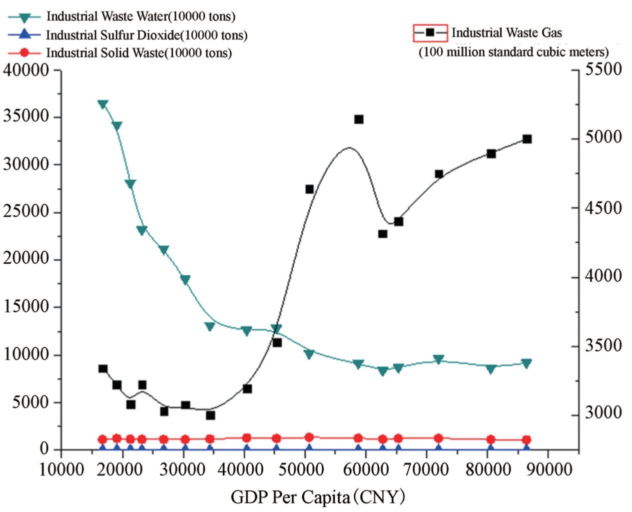

Figure 8
The Double Y Figure of Beijing

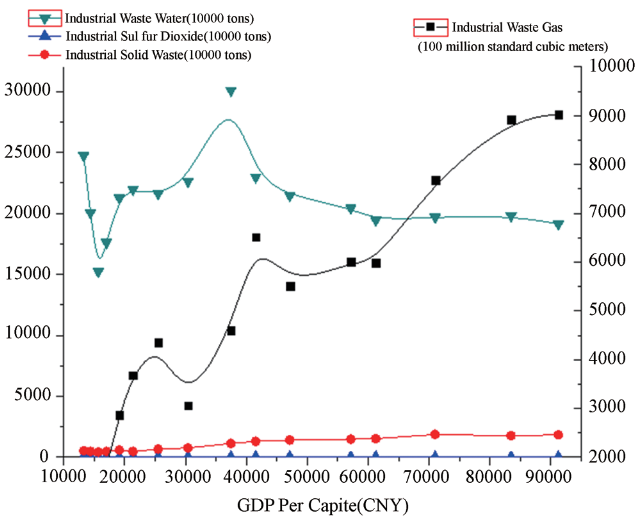

Figure 9
The Double Y Figure of Tianjin

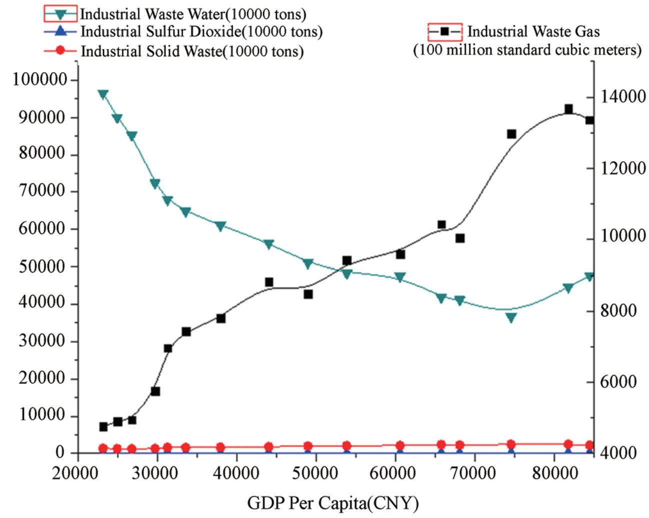

Figure 10
The Double Y Figure of Shanghai

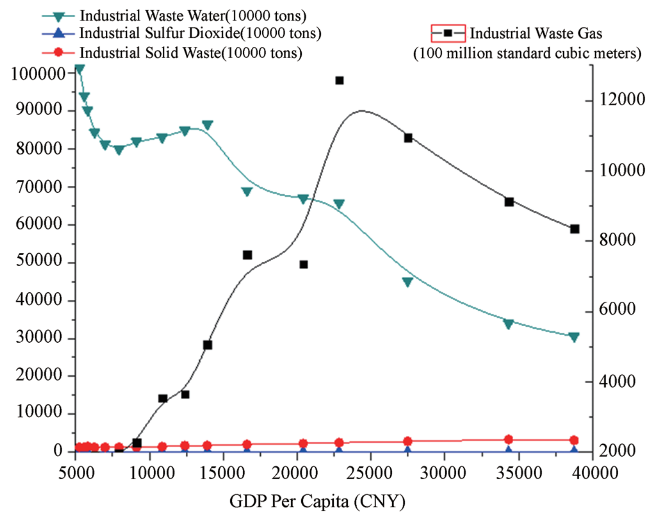

Figure 11
The Double Y Figure of Chongqing

From the diagrams above, it is easy to distinguish that discharge of industrial waste water and GDP per capita, emission of industrial waste gas and GDP per capita do have certain functional relations. Specifically, there is a decreasing relationship between industrial waste water and GDP per capita in Beijing, Shanghai and Chongqing. And an rising trend exists between industrial waste gas and GDP per capita in Beijing, Tianjin and Shanghai.

However, due to smaller orders of magnitude, it is hard for us to distinguish whether emission of industrial sulfur (SO_2) and GDP per capita, discharge of industrial solid waste and GDP per capita have certain functional relations. So we draw the double Y figures between the two pollutants and GDP per capita, as shown in Figure 12 to Figure 15.

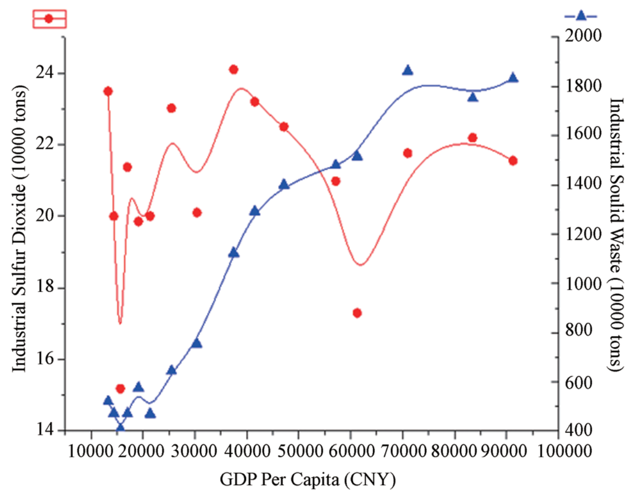

Figure 12
The Double Y Figure of Beijing

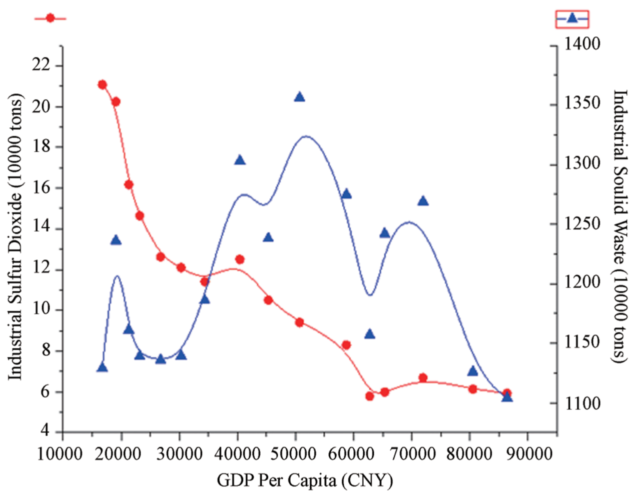

Figure 13
The Double Y Figure of Tianjin

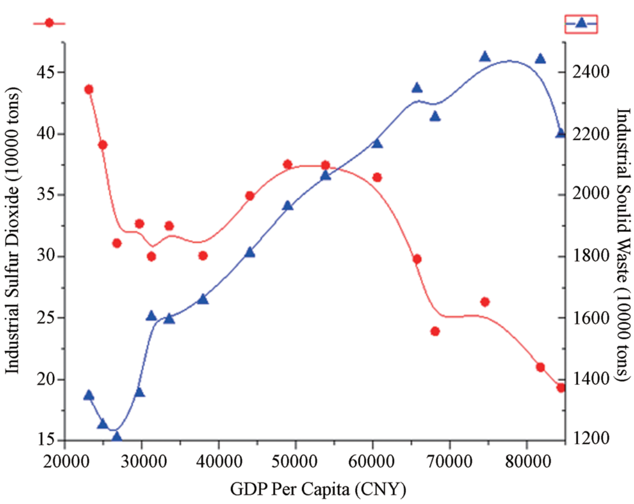

Figure 14
The Double Y Figure of Shanghai

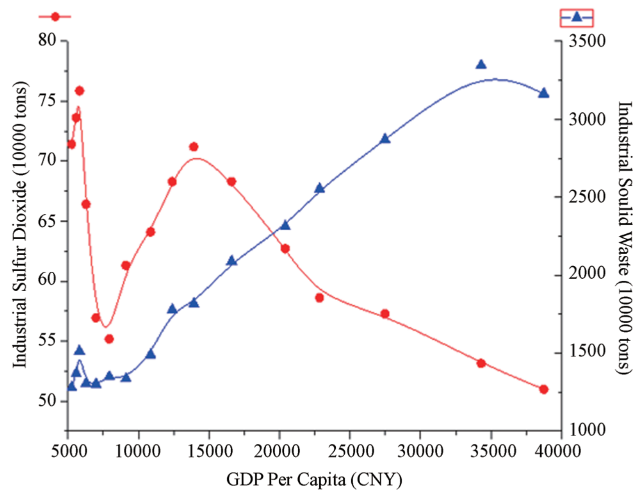

Figure 15
The Double Y Figure of Chongqing

From the figures above, we can easily find that emission of industrial sulfur dioxide (SO_2) and GDP per capita, discharge of industrial solid waste and GDP per capita do have one or another relationship.

3.2 The Empirical Test

According to Equation (1), we conduct the empirical study with SPSS software. Here are summary of the regression results between discharge of industrial waste water and GDP per capita, as shown in Table 2.

Table 2 tells us the following information: the goodness of fit (namely R^2) in Beijing, Shanghai and Chongqing separately is 0.978, 0.967 and 0.930, which proves that the cubic equation is adopted to fit the experiment data in good effect. However, as a result of unremarkable t value in Chongqing, so only Beijing and Shanghai's fitted curves are acceptable. Besides, both Beijing and Shanghai's coefficients are $\hat{a}_1 < 0, \hat{a}_2 > 0, \hat{a}_3 < 0$, so the curves are inverted N shape.

By further calculation, we find that Beijing has two extreme points: when Beijing's GDP per capita was 55911.783 CNY, discharge of industrial waste water reached the minimum value; when GDP per capita reached 74192.474 CNY, the maximum value would appear. In 2011, Beijing's GDP per capita had amounted to 80510.75 CNY, so discharge of industrial waste water at present is in the stage of declining, as shown in Figure 16. This phenomenon is partly attributable to Beijing Green Olympics in 2008, along with widely cleaning up the environment and carrying out environmental education.

Similarly, Shanghai also has two extreme points: when Shanghai's GDP per capita was separately 67660.343 CNY and 90784.620 CNY, discharge of industrial waste water accordingly reached the minimum and the maximum value. In 2012, GDP per capita in Shanghai was 84459.33 CNY, discharge of industrial waste water had not reached the maximum value, as shown in Figure 17. So before the environment gets much worse, Shanghai should strengthen environmental protection.

Table 2
The Regression Results Between Discharge of Industrial Waste Water and GDP Per Capita

Municipalities	Regression function	Statistical indexes	Significant or not	Curve shape
Beijing	Y=77353.422-3.263x+5.117E-5x^2-2.622E-10x^3 t value =15.105 -8.722 6.426 -5.104	R^2=0.978 DW=1.50 F=180.7	Yes	Inverted N-shape
Tianjin	Y=9770.363+0.918x-1.862E-5x^2+1.067E-10x^3 t value =1.508 1.733 -1.575 1.391	R^2=0.280 DW=1.54 F=1.553	No	N-shape
Shanghai	Y=192756.458-5.895x+7.603E-5x^2-3.199E-10x^3 t value =8.536 -4.009 2.608 -1.779	R^2=0.967 DW=1.04 F=118.3	Yes	Inverted N-shape
Chongqing	Y=92156.470+0.085x-9.412E-5x^2+1.282E-9Y^3 t value =8.156 0.037 -0.751 0.652	R^2=0.930 DW=1.08 F=53.06	No	N-shape

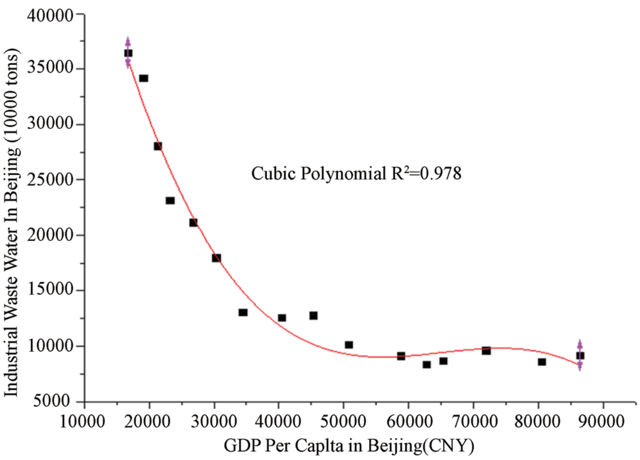

Figure 16
The Fitting Curve of Beijing

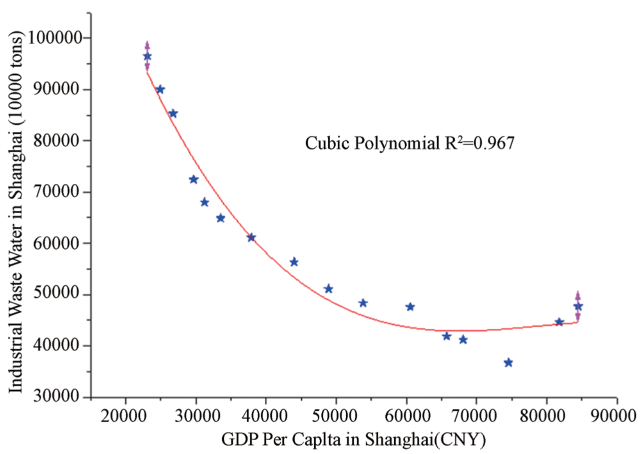

Figure 17
The Fitting Curve of Shanghai

In addition, the curves of Tianjin and Chongqing are shown in N shape with two extreme points. In 2011, GDP per capita in Tianjin exceeded 80880.91 CNY that corresponded to the minimum value of discharge of industrial waste water. So with further growth of economy, the environment in Tianjin will deteriorate, as shown in Figure 18. Although the results are not statistically significant, the government should also pay close attention to it.

In 2012, Chongqing's GDP per capita was 8742.28 CNY, less than 48488.562 CNY, so discharge of industrial waste water did not reach the minimum value. Up till now, this environmental indicator is still falling, as shown in Figure 19, and we must be alert to the arrival of its future rise.

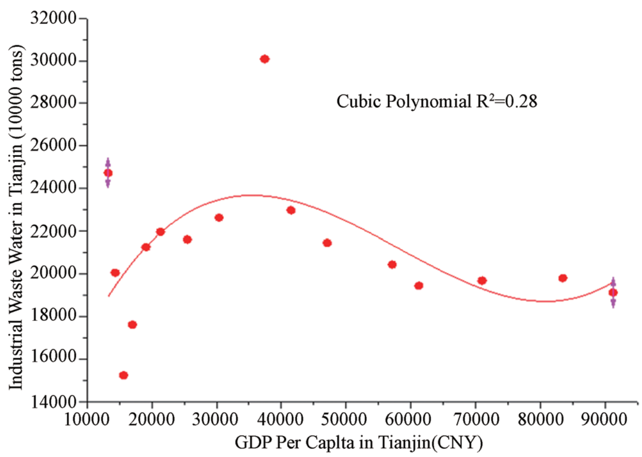

Figure 18
The Fitting Curve of Tianjin

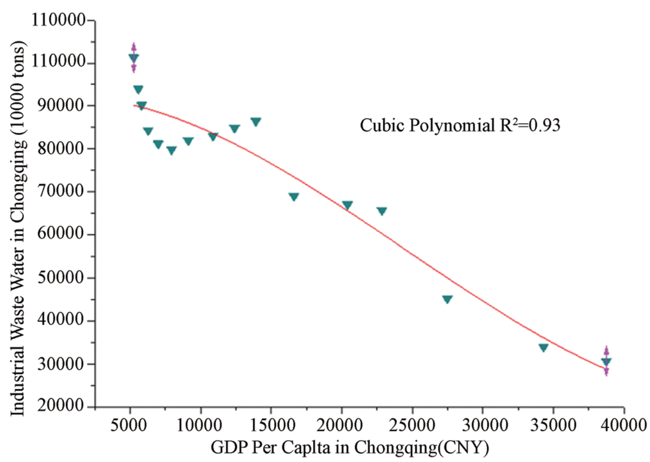

Figure 19
The Fitting Curve of Chongqing

Table 3
The Regression Results Between Emission of Industrial Waste Gas and GDP Per Capita

Municipalities	Regression function	Statistical indexes	Significant or not	Curve shape
Beijing	Y=5042.943-0.171x+4.3964E-6x^2-2.839E-11x^3 t value = 4.500 -2.084 2.524 -2.526	R^2=0.864 DW=1.397 F=25.336	yes	Inverted N-shape
Tianjin	Y=-1863.34+0.307x-4.282E-6x^2+2.484E-11x^3 t value = -1.295 2.613 -1.632 1.458	R^2=0.941 DW=2.074 F=64.248	yes	N-shape
Shanghai	Y=-7159.749+0.746x-1.219E-5x^2+7.492E-11x^3 t value = -2.203 3.242 -2.671 2.662	R^2=0.968 DW=2.089 F=122.22	yes	N-shape
Chongqing	Y=1140.789-0.154x+4.564E-5x^2-9.651E-10x^3 t value = 0.572 -0.381 2.063 -2.783	R^2=0.931 DW=2.846 F=53.773	yes	Inverted N-shape

Table 4
The Regression Results Between Emission of Industrial Sulfur Dioxide and GDP Per Capita

Municipalities	Regression function	Statistical indexes	Significant or not	Curve shape
Beijing	Y=33.764-0.001x+1.466E-8x^2-7.181E-14x^3 t value = 6.988 -2.998 1.952 -1.482	R^2=0.929 DW=0.972 F=52.263	yes	Inverted N-shape
Tianjin	Y=14.575-1.038E-8x^2+6.388E-14x^3 t value = 2.869 -1.12 1.062	R^2=0.129 DW=2.134 F=0.591	no	N-shape
Shanghai	Y=72.666-0.003x+5.348E-8x^2-3.685E-13x^3 t value = 2.892 -1.56 1.648 -1.841	R^2=0.688 DW=1.040 F=8.827	yes	Inverted N-shape
Chongqing	Y=70.538+1.805E-8x^2-4.209E-13x^3 t value = 6.141 0.142 -0.211	R^2=0.465 DW=0.659 F=3.479	no	Inverted N-shape

Table 5
The Regression Results Between Discharge of Industrial Solid Waste and GDP Per Capita

Municipalities	Regression function	Statistical indexes	Significant or not	Curve shape
Beijing	Y=1127.677-0.001x+1.768E-7x^2-1.930E-12x^3 t value = 5.793 -0.097 0.584 -0.988	R^2=0.505 DW=2.030 F=4.080	no	Inverted N
Tianjin	Y=164.506+0.013x+4.332E-7x^2-4.199E-12x^3 t value = 0.794 0.775 1.146 -1.710	R^2=0.974 DW=1.686 F=149.97	yes	Inverted U
Shanghai	Y=993.932-0.004x+8.248E-7x^2-7.069E-12x^3 t value = 1.831 -0.106 1.176 -1.630	R^2=0.966 DW=1.843 F=112.88	yes	Inverted N
Chongqing	Y=1417.209-0.053x+7.370E-6x^2-1.243E-10x^3 t value = 8.354 -1.537 3.916 -4.214	R^2=0.987 DW=1.830 F=292.42	yes	Inverted N

Likewise, we do the empirical research between the other three environmental pollution indicators and GDP per capita under Eq (1), the results are shown in Table 3-5.

3.3 Summary of Empirical Study

By summarizing the empirical results, we draw Table 6 as follows.

Table 6
Summary of the EKC Shape

Municipality	Industrial waste water (10000 tons)		Industrial waste gas (100 million standard m^3)		Industrial SO_2 (10000 tons)		Industrial solid waste (10000 tons)	
	Significance	Shape	Significance	Shape	Significance	Shape	Significance	Shape
Beijing	Yes	Inverted N	Yes	Inverted N	Yes	Inverted N	No	Inverted N
Tianjin	No	N shape	Yes	N shape	No	N shape	Yes	Inverted U
Shanghai	Yes	Inverted N	Yes	N shape	Yes	Inverted N	Yes	Inverted N
Chongqing	No	N shape	Yes	Inverted N	No	Inverted N	Yes	Inverted N

From Table 6 we can learn that Beijing's EKC curves are all inverted N shape and most of them are statistically significant. Moreover, emissions of the pollutants basically have a downward tendency, which means that Beijing's environment is gradually improving.

Speaking of Tianjin, since the regression results between industrial solid waste and GDP per capita are $\hat{a}_1 > 0, \hat{a}_2 > 0, \hat{a}_3 > 0$, so it does not meet any situation of the seven above. By combining with the equation, we can determine that the curve is inverted U shape, while the shapes between the other three indicators and GDP per capita are all N curves.

Shanghai and Chongqing's EKC curves are mainly inverted N shape, accompanying with N shape at the same time. The different point is that Shanghai's statistical indicators are all statistically significant while Chongqing's not. For one thing, Chongqing should further accelerate economic development under the premise of protecting environment so as to narrow the economic gap with the other three municipalities. For another thing, Shanghai should balance the relationship between environmental protection and economic development, so that turn Shanghai into the apple of the whole world's eye.

CONCLUSION

By conducting the empirical study between environmental pollution and economic growth in China's four municipalities, we can draw the following conclusions:

(1) The relation between economic growth and environmental pollution has many forms, inverted U shape is only one of them. The empirical results are rich in N shape and inverted N shape, which means that the relationship between environmental pollution and economic growth in China's municipalities is complex, rather than stereotypical.

(2) With the development of social economy, environmental conditions may not improve by itself. Besides, both changes of environmental policy and adjustments of industrial structure are likely to have an impact on the environment.

In order to promote the harmony between economic development and environmental protection, our suggestions are as follows:

(1) Further increase the investment in environmental protection.

(2) Optimize the industrial structure and transform the mode of economic growth.

(3) Develop new clean energy and promote the market operation of environmental protection.

(4) Carry out environmental education and propaganda activities so as to strengthen the public's environmental protection consciousness.

(5) Perfect the relevant legal policy, such as implementation of green tax.

(6) Attach great importance to science and promote technology innovation.

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APPENDIX

A. The Indicators of Beijing

Year	GDP Per Capita (CNY)	Industrial waste water (10000 tons)	Industrial waste gas (100 million standard m^3)	Industrial SO_2 (10000 tons)	Industrial solid waste (10000 tons)
1997	16750.81	36478	3342	21.08	1129.00
1998	19084.78	34196	3227	20.24	1236.00
1999	21307.67	28085	3083	16.17	1161.00
2000	23186.42	23164	3227	14.64	1139.00
2001	26770.63	21165	3035	12.63	1136.00
2002	30319.00	18000	3080	12.10	1139.30
2003	34380.66	13107	3005	11.40	1186.00
2004	40418.03	12617	3198	12.50	1303.00
2005	45315.34	12813	3532	10.50	1238.00
2006	50704.56	10170	4641	9.40	1356.00
2007	58751.79	9134	5146	8.30	1274.80
2008	62761.15	8367	4316	5.78	1157.00
2009	65338.71	8713	4408	5.99	1242.00
2010	71938.43	9653	4750	6.69	1268.90
2011	80510.75	8633	4897	6.13	1126.00
2012	86403.13	9190	5000	5.93	1104.05

Note. Sources of data: Beijing statistical yearbook and China environmental statistics.

B. The Indicators of Tianjin

Year	GDP Per Capita (CNY)	Industrial waste water (10000 tons)	Industrial waste gas (100 million standard m^3)	Industrial SO_2 (10000 tons)	Industrial solid waste (10000 tons)
1997	13275.70	24727	1729	23.49	520.00
1998	14369.04	20046	1644	20.00	472.00
1999	15643.37	15221	1570	15.18	407.00
2000	16999.42	17604	1749	21.37	470.00
2001	19113.30	21250	2858	19.85	575.00
2002	21354.28	21959	3678	20.00	469.80
2003	25492.24	21605	4360	23.02	644.00
2004	30390.36	22628	3058	20.10	753.00
2005	37446.21	30081	4602	24.10	1123.00
2006	41513.86	22978	6512	23.20	1292.00
2007	47109.96	21444	5506	22.50	1399.40
2008	57134.44	20433	6005	20.98	1479.00
2009	61244.87	19441	5983	17.30	1516.00
2010	70996.16	19679	7686	21.76	1862.40
2011	83474.43	19795	8919	22.19	1752.00
2012	91242.12	19117	9032	21.55	1831.00

Note. Sources of data: Tianjin statistical yearbook and China environmental statistics.

C. The Indicators of Shanghai

Year	GDP Per Capita (CNY)	Industrial waste water (10000 tons)	Industrial waste gas (100 million standard m^3)	Industrial SO_2 (10000 tons)	Industrial solid waste (10000 tons)
1997	23094.63	96544	4755	43.62	1347.60
1998	24892.53	90000	4912	39.09	1252.40
1999	26730.89	85280	4947	31.09	1211.10
2000	29660.39	72446	5755	32.68	1354.74
2001	31229.55	68012	6964	30.01	1605.00
2002	33515.06	64900	7440	32.49	1595.30
2003	37909.61	61112	7799	30.07	1659.40
2004	43994.10	56359	8834	34.95	1811.00
2005	48922.69	51097	8482	37.52	1964.00
2006	53827.13	48336	9428	37.43	2063.00
2007	60545.31	47570	9591	36.44	2165.40
2008	65727.09	41871	10436	29.80	2347.00
2009	68074.86	41192	10059	23.93	2255.00
2010	74548.48	36696	12969	26.32	2448.36
2011	81772.17	44626	13692	21.01	2442.20
2012	84459.33	47700	13361	19.34	2198.81

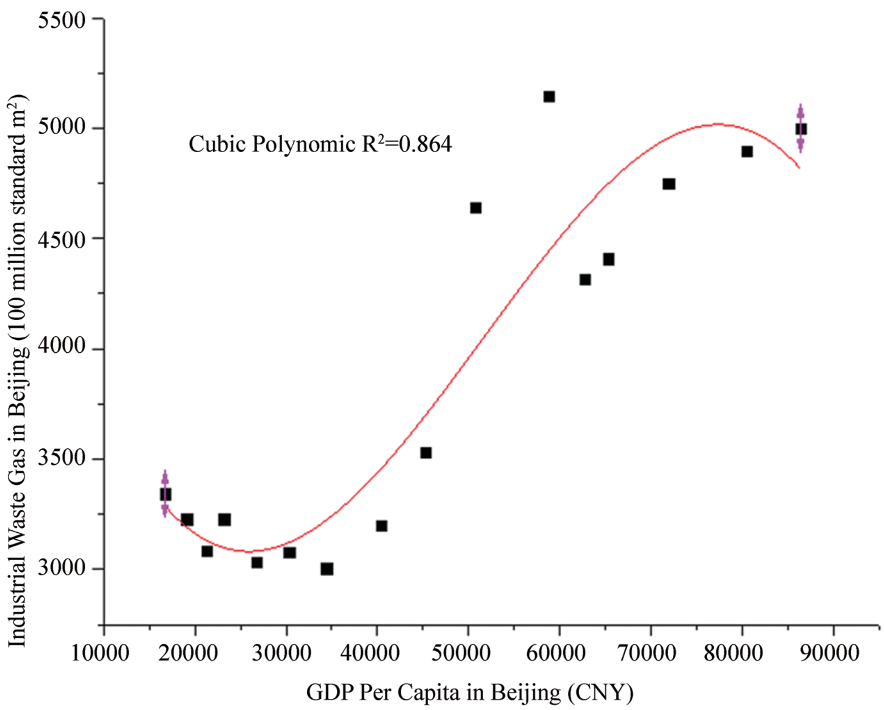
Note. Sources of data: Shanghai statistical yearbook and China environmental statistics.

D. The Indicators of Chongqing

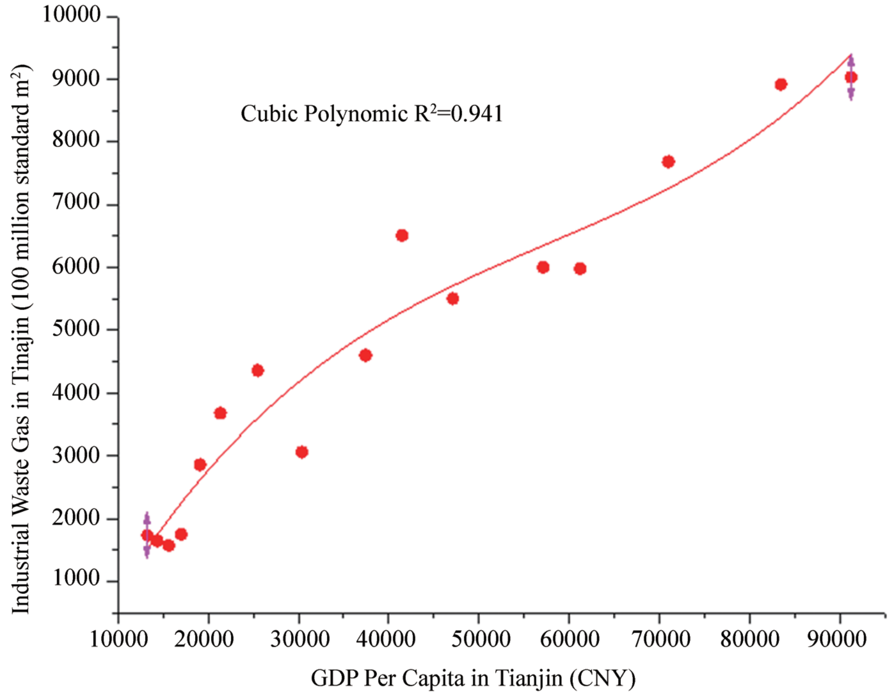
Year	GDP Per Capita (CNY)	Industrial waste water (10000 tons)	Industrial waste gas (100 million standard m^3)	Industrial SO_2 (10000 tons)	Industrial solid waste (10000 tons)
1997	5254.30	101300	1794.00	71.43	1279.00
1998	5581.75	94000	1712.76	73.64	1368.00
1999	5814.63	90220	1839.33	75.88	1512.00
2000	6286.81	84344	1907.90	66.42	1305.00
2001	6987.32	81214	1856.24	56.94	1300.00
2002	7932.49	79900	1978.89	55.18	1348.00
2003	9117.18	81973	2276.94	61.31	1336.00
2004	10863.70	83031	3540.86	64.10	1489.00
2005	12393.57	84885	3654.55	68.30	1777.00
2006	13914.64	86496	5066.96	71.20	1815.00
2007	16605.58	69003	7616.62	68.30	2087.00
2008	20407.40	67027	7350.73	62.72	2311.00
2009	22840.19	65684	12586.52	58.61	2552.00
2010	27475.30	45180	10943.13	57.27	2869.00
2011	34297.26	33954	9121.07	53.13	3345.68
2012	38742.28	30600	8359.88	50.98	3163.91

Note. Sources of data: Chongqing statistical yearbook and China environmental statistics

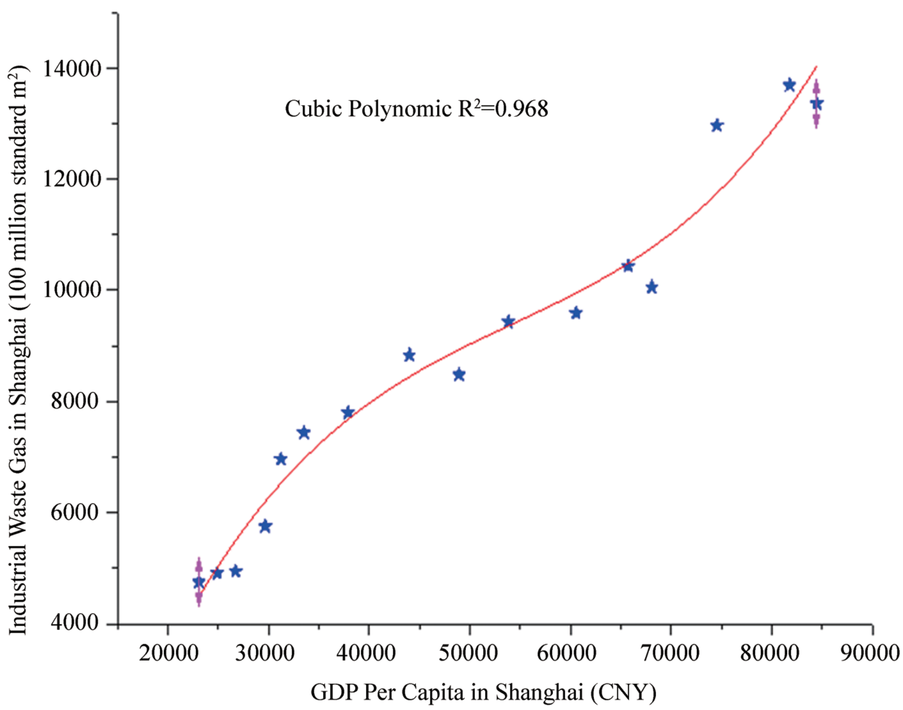
E. The Fitting Curve Between Industrial Waster Gas and GDP Per Capita



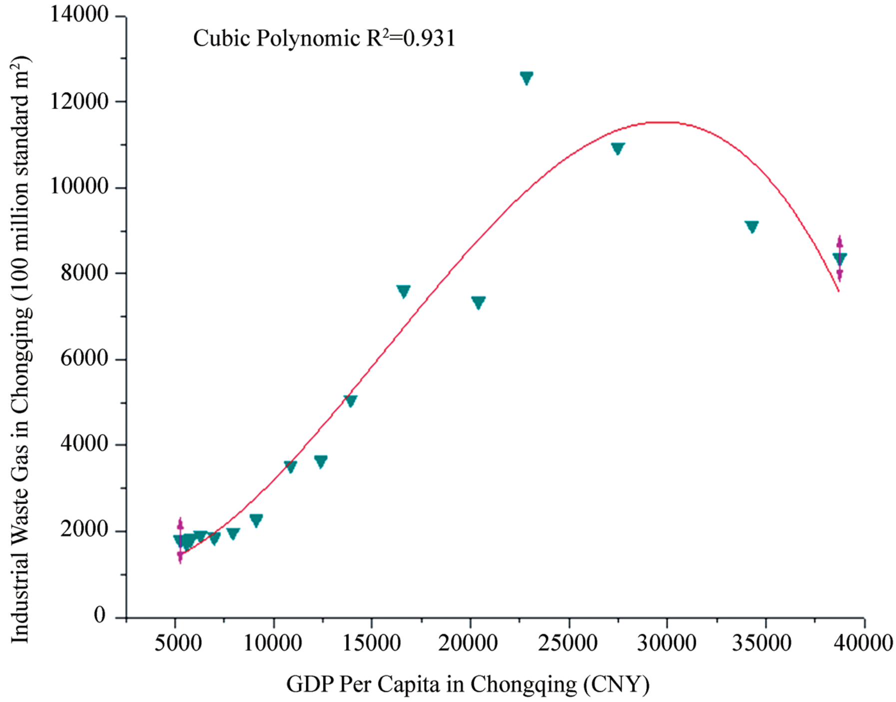
Beijing



Tianjin

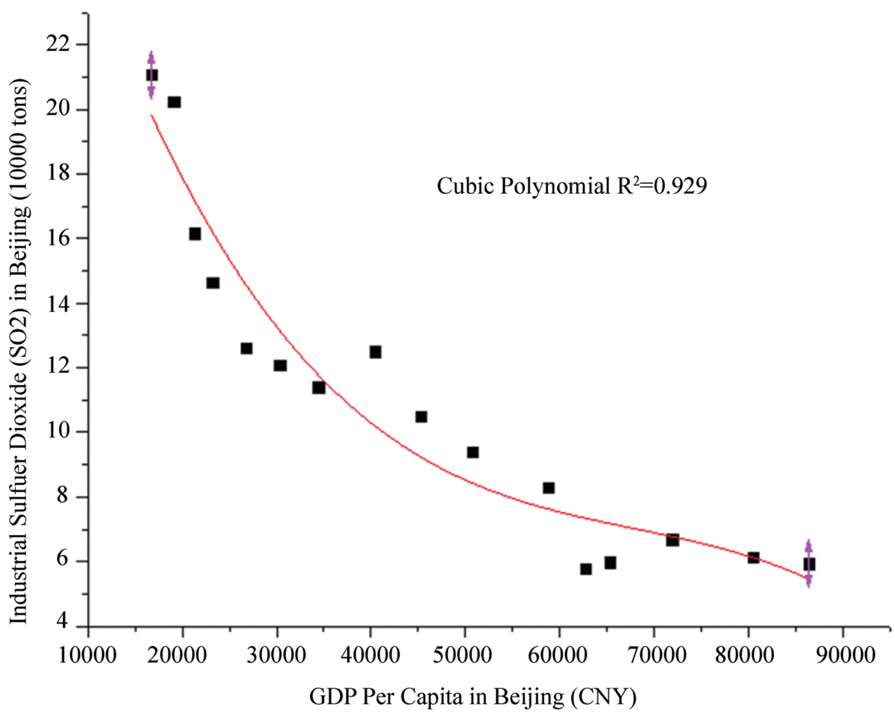


Shanghai

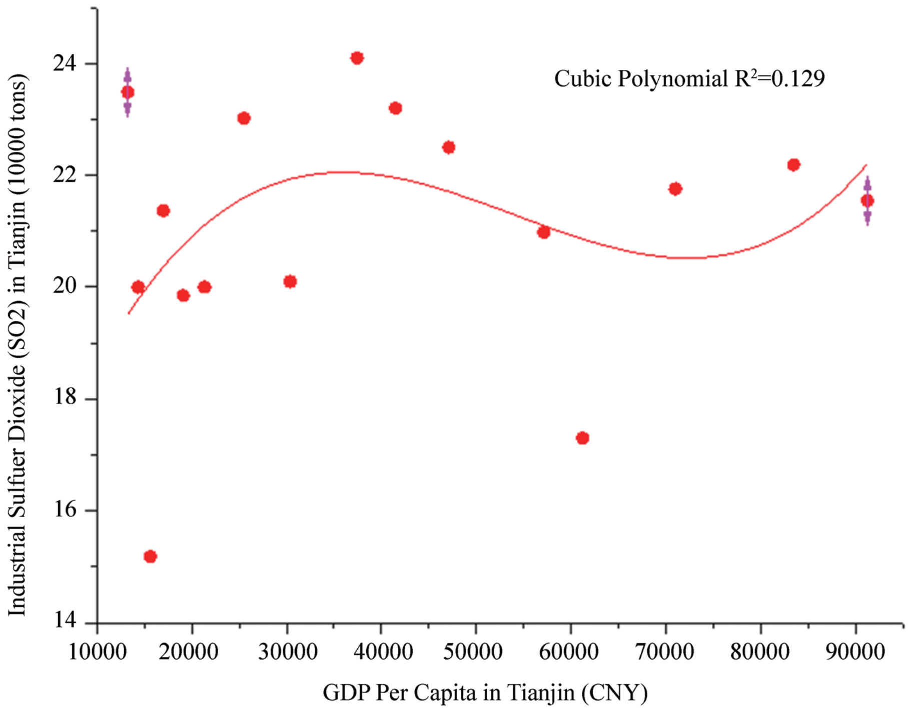


Chongqing

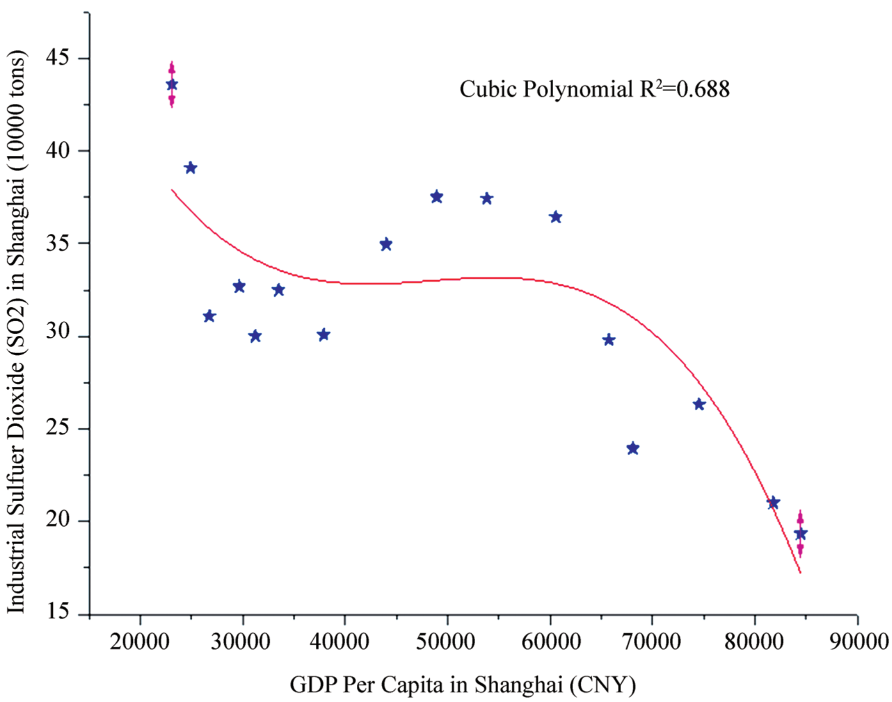
F. The Fitting Curve Between Industrial SO_2 and GDP Per Capita



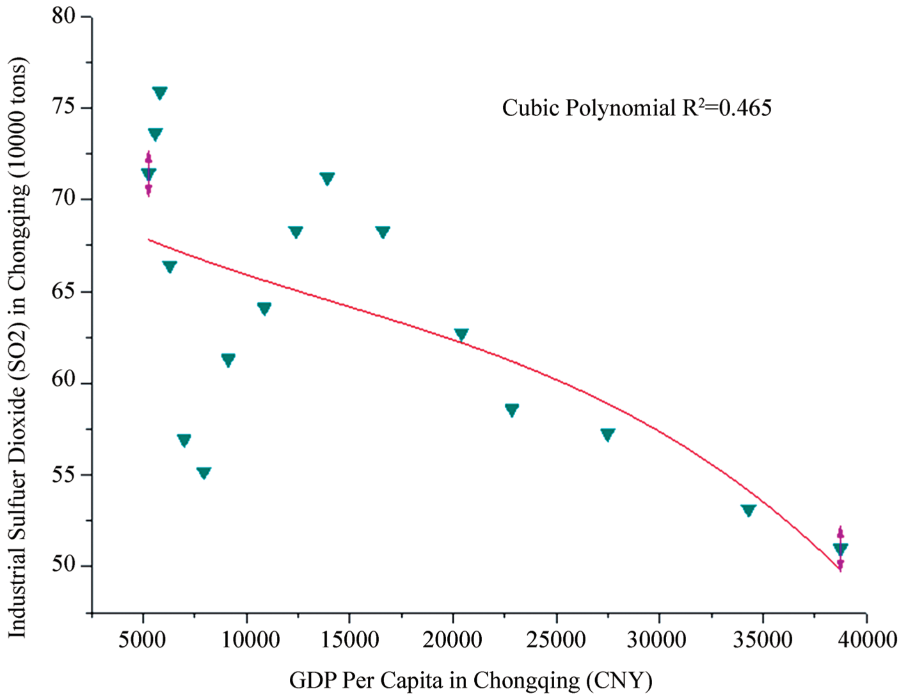
Beijing



Tianjin

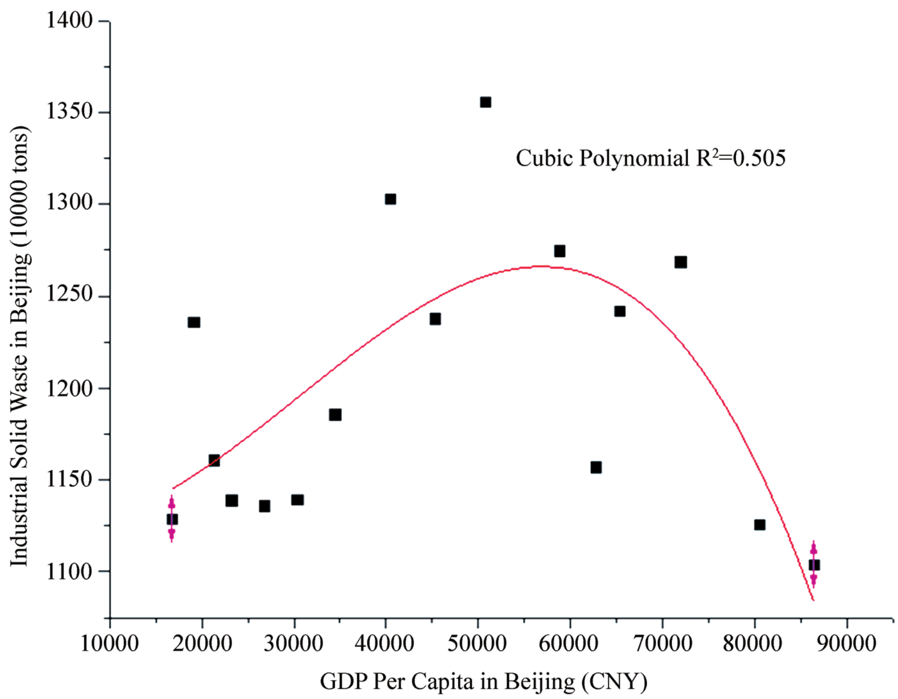


Shanghai

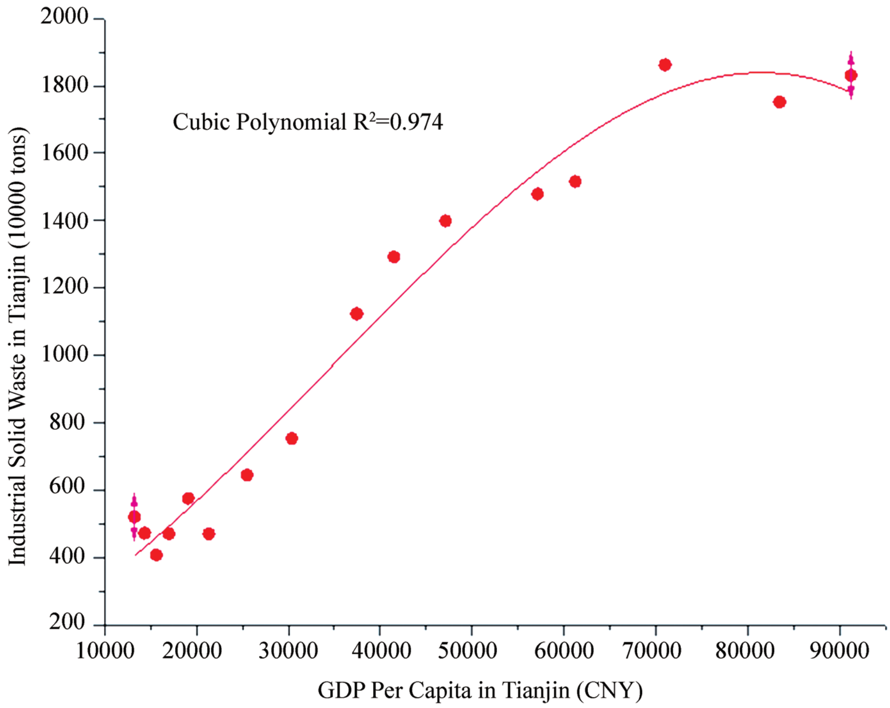


Chongqing

G. The Fitting Curve Between Industrial Solid Waste and GDP Per Capita



Beijing



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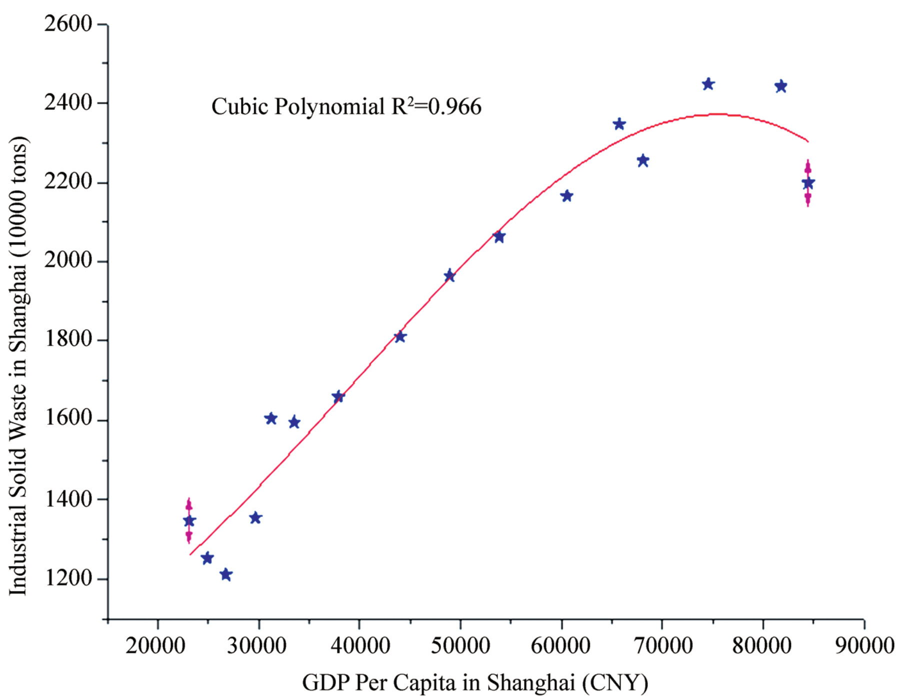
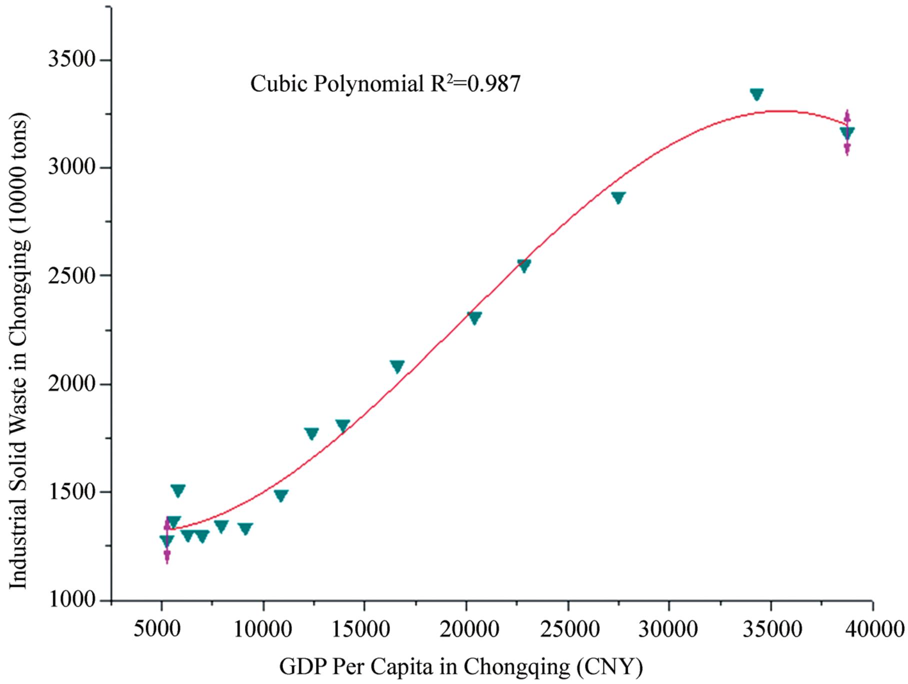


Shanghai


Cubic Polynomial R²=0.987
Industrial Solid Waste in Chongqing (10000 tons)
GDP Per Capita in Chongqing (CNY)
1000
1500
2000
2500
3000
3500
5000
10000
15000
20000
25000
30000
35000
40000

Chongqing

