ECONOMIC GROWTH AND ENVIRONMENTAL DEGRADATION
An Empirical Study on Pollution in Sichuan Province

Yunxi Hu

8586728

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Supervisor: Professor Nguyen Van. Quyen

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ABSTRACT

The paper is an empirical study on the relationship between economic growth and pollution, using the data from the province of Sichuan, China. Three pollutants – industrial wastewater, industrial solid wastes, and industrial gas waste – are considered. The results – obtained from the Johansen co-integration test and the Granger causality test – indicate that both industrial wastewater and industrial solid waste have a negative impact on economic growth, but not industrial gas waste.

1. INTRODUCTION

In an economy, the production uses energy, labor, capital, and raw materials to produce goods and services. The environment plays an important role in the economy. In the production of goods and services, raw materials, such as metals, minerals, water, tree, etc. are extracted from the environment. Energy resources – coal, oil, natural gas – are also extracted from the environment required to transform raw materials into goods and services – intermediate as well as final consumption goods. In addition, the environment acts to provide many ecosystem services, such as filtering air pollution, sequestering carbon, and protect against flood risk. It also provides us with recreational activities and improves our health. Economic growth is an important driver of the economy. It stimulates consumption and advances production. It makes improvements in health, education, and life quality possible. It is also vital for the wellbeing of the economy and its citizens in both developed and developing world. (Richard Price, 2010, p.12).

According to the first law of thermodynamics, matter can never be destroyed or created: the materials and energy that do not go into the final product are returned to the environment as wastes. The wastes can also come from consumption. When people drive cars, the exhaust from the cars adds to the stock of greenhouse gases in the atmosphere. The environment thus acts as a supplier of resources and a receptor of waste products.

With the development of society and economic growth, the attendant environment pollution has become a serious issue. There are those who argue that Industrialization and urbanization eventually leads to environmental degradation (Peng, 2006), while others contend that economic growth and environment quality interact with each other and will be promoting each other mutually (Beckerman, 1992). No clear-cut conclusion has emerged from the debate, and the issue still needs to be studied further.

There is no denying that economic growth brings many benefits. However, the ever-increasing scale of production also degrades ecosystems and depletes natural resources. The debate is whether or not it is possible to achieve sustainable economic growth without the degradation of the ecosystems and the depletion of the natural resources. As a result of human activities, the level of carbon dioxide (CO_2) in the atmosphere has being rising dramatically, and the world is facing the great challenge of keeping the rise in the global temperature below two degrees. Researchers have found that 15 out of 24 ecosystems were used unsustainably, and the consumption of natural resources such as metals and minerals was rising at an increasing rate (Millennium Ecosystem Assessment, 2003). Some take the view that the cost of inaction would be far greater than the cost of action now, and using environmental resources sustainably is consistent with the economic growth. Others think that the stocks of natural resources are finite, and this places a limit on the extent to which the economy could expand.

There is a large body of empirical studies on the relationship between income and some measures of environmental qualities. The regression model used in the empirical studies typically link GDP per capita – the dependent variable – to three independent variables – industrial waste water, industrial solid waste, and industrial gas waste –

which represent the environmental quality. The World Bank Development Report (1992) relates the percentage of the population that has no access to safe water or urban sanitation to the level of income by using internal World Bank data and carries out an analysis on the relationship between income and municipal solid waste per capita, using OECD and World Resources Institute estimates for 39 countries in 1985. Seldon (1992) uses a similar method to investigate the relationship between the estimated rate of emission of several air pollutants with the country's national income. These studies tend to find an inverted "U" relationship between environmental quality and level of income.

This paper is an empirical study on the relationship between pollution and economic growth for Sichuan, a province of China. The main employs reliable data and a common methodology to investigate the relationship between the scale of economic activities and environmental quality for a broad set of environmental indicators. We use the available data from the "Statistical Yearbook of Sichuan Province",[1] which tracks industrial wastes, in order to include dimensions of environmental quality of which actual measurements have been taken by comparable methods in other analyses. Though these measures are far from comprehensive, they at least represent the largest part of the relevant variables as industrial production process cause the majority of environmental pollution. The main results that come out of our analysis is that indicators of environmental quality no longer exhibit an inverted "U" relationship with GDP per capita: industrial water waste and industrial solid waste show an "N" relationship with

[1] Source: http://www.sc.stats.gov.cn/tjcbw/tjnj/

GDP per capita, and industrial gas waste exhibits no linear or nonlinear relationship with GDP per capita.

The paper is organized as follows. In Section 2, the most prominent hypothesis linking environmental degradation an economic growth – the environmental Kuznets curve (EKC) – is presented. Most empirical studies on the linkages between economic growth and environment are dedicated to confirming or rejecting the EKC. Section 3 is a short review of the empirical literature on the relationships between pollutants and economic growth. A theoretical model of production and pollution is presented in Section 4. The econometric model is presented in Section 5. The results of the Johansen co-integration test as well as the Granger causality test are presented in Section 6. In this section, the main results of the paper are discussed. Section 7 contains some concluding remarks. The data and the results of some tests are relegated to several appendices.

2. THE ENVIRONMENTAL KUZNETS CURVE

In the 1950s, the American economist Kuznets (1955) examined the relationship between the economic growth (level of income per capita) and income inequality, and drew the conclusion that as the economy embarks on its development path, income inequality would firstly widen, and then gradually narrows down after the economy reaches a certain stage. That is, income inequality exhibits an inverted U shape, when plotted against income.

Forty years later, another American economist, Grossman and Krueger (1991) suggested an inverted U-shape relationship between GDP per capita and many pollutants by analyzing panel data from 42 countries in the world. The intuitive logic behind the EKC can be explained as follows. At low levels of income, the limited income is devoted to meeting the basic needs of the population. As income rises, and basic needs have been fulfilled, the quality of the environment – a particular type of good – might yield more utility than an additional unit of consumption, and resources will be deemed to be better used in pollution abatement than in consumption, with the ensuing consequence that environmental quality now rise with economic growth.

The environmental Kuznets curve (EKC) – named after Kuznets, but not developed by this researcher – hypothesizes an inverted U-shaped relationship between economic development and environment quality. The hypothesis asserts that pollution rises in the early stages of economic development, but the trend is reversed after GDP per capital surpasses a certain level. Figure 1 depicts the EKC, when the level of environmental degradation is plotted against GDP per capita.

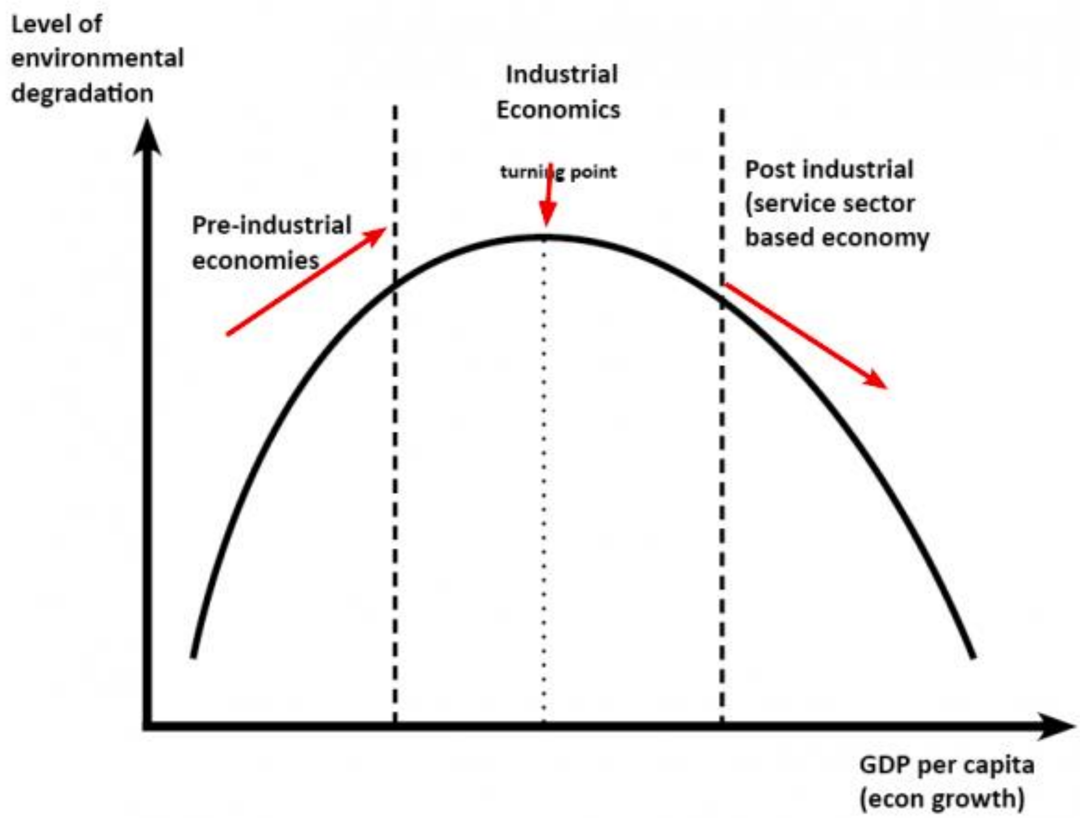

Figure 1.-Environmental Kuznets Curve (inverted “U” shape)

3. LITERATURE REVIEW

Most empirical studies on the linkages between environment and economic growth attempt to test the EKC hypothesis.

Shafik and Bandyopadhyay (1992) discovered that emissions of sulfur dioxide (SO_2) originally increased and then reduced as income per capital rises, confirming the EKC hypothesis. Panayotou (1993), who conducted an analysis on forest deforestation and rising income, found an inverted U-shape relationship between the two variables. Seldon and Song (1994) confirmed the existence of the EKC by analyzing the relationship between CO_2, SO_2, NO_2, $CO,$ and suspended particular matter. Guo and Li

(2010) in conducted an empirical study on the linkages between pollutants and economic growth, using panel data on 29 provinces of China, and concluded that industrial solid waste (ISW) and GDP per capita were in line with the EKC.

Not all the empirical studies on the linkages between economic growth and environment support the EKC hypothesis. Zhou, Yuan, and Xue (2009) carried out a study on Shanxi province, using the industrial wastewater and GDP per capita, and the results they obtained showed that the two variables exhibit a stable long-run N-shape relationship. The same results were found by Ding (2012), who used data in on Guangxi Province. Wang (2013), in a study on a costal area economy and marine environmental pollution, found an N-shaped curve. Figure 2 depicts the N-shaped relationship between per capital income and environmental degradation.

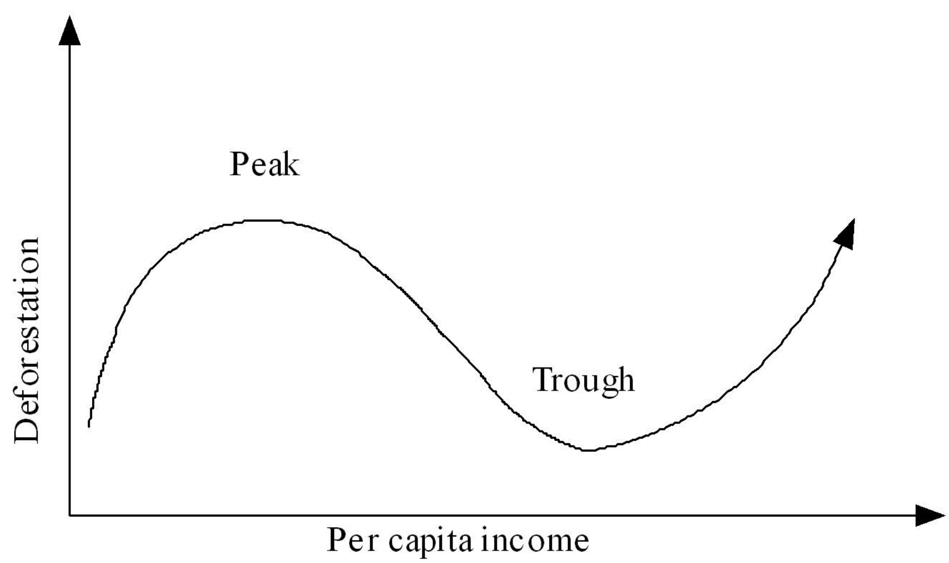

Figure 2.-Environmental Kuznets curve (“N” shape)

Gene and Alan (1995) used environmental indicators, such as urban air pollution, the oxygen regime state in river, fecal contamination of river, and contamination of river by heavy metals, to represent environmental quality in studying the linkages between economic growth and the environment. They found that environmental quality does not steadily deteriorate with economic growth. Furthermore, economic growth first brings deterioration to most indicators, and then improvement after that. The turning points of different indicators vary, but in general, they are around the GDP per capita of $8000; see Grossman and Krueger (1995).

Shaik Feroz (2014) formulated a VAR model and used the variance decomposition method to investigate the long-term relationships between environmental pollution indicators and GDP per capita in western China from 1992 to 2010. This researcher concludes that economic growth is a major cause of environmental pollution and that there is also a reverse effect. However, the reverse effect is not immediate, but has a lag. In addition, the variance decomposition shows that economic growth has little explanatory power for the different kinds of the environmental pollution indicators. The paper shows that the original EKC hypothesis of EKC cannot be generalized to the global level since the empirical evidence only shows the results for developed countries. What is even more striking is that there is no correlation between higher levels of income and lower gas emissions (including six atmospheric pollutants in Spain), except for SO_2. The author argues that the relationship between income level and types of emissions may depend on many factors.

In a paper entitled “Economic Growth and Environmental Pollution in Myanmar: An Analysis of Environmental Kuznets Curve,” Aung et. Al (2007) tested the validity of the EKC, and investigated the short-run as well as the long-run relationships between environmental pollution indicators and economic indicators. The environmental pollution indicators are $CO_2, CH_4, N_2O,$ and the economic growth indicators are GDP. The authors also considered other proxies, such as trade intensity and financial openness, urbanization and structural breaks in the country. The authors used annual data in Myanmar over the period 1970-2014, and carried out the analysis using an autoregressive distributed lag (ARDL) model. The empirical results show an absence of the EKC for CO_2 and GDP, while evidence of the EKC is found for CH_4 and N_2O. The authors finally concluded that financial openness and trade liberation will contribute to the environment improvement in the long-run.

Omisakin (2009) argued that environment pollution is inevitable in developing countries. According to this author, the developing countries are at an early stage on the EKC because developing countries desire economic growth and tend to consume cheaper sources of energy. Massive infrastructures, such as roads and rail tracks, are in heavy need to promote industrialization. These activities at the take-off stage of economic development are substantially energy intensive. And the concluded that compelling developing countries to pursue environment goals requires substantial financial and technological support from developed countries to compensate for the losses associated with pollution reduction.

George E. Halkos (2003), in a paper entitled “Growth and Environmental Pollution: Empirical Evidence from China,” investigated the relationship between CO_2 and GDP per capita by using time series data from 1960 to 2006, with additional variables in trade and agriculture, industry and services sectors. The results indicate an inverted “U” shape relationship between CO_2 and GDP per capita and that trade is also a determinant of pollution.

Luo et al. (2014), in a research paper entitled ”Relationship Between Air Pollutants and Economic Development of the Provincial Capital Cities in China during the Past Decade,” chose GRP per capita (Gross Regional Product per capita) as economic indicators, and PM_{10}, SO_2, NO_2 and the air pollution index (API) as air pollutants indicators to find out if there is an EKC between the economic indicator and the pollutant indicators. The analysis was conducted by using the 31 provinces’ data over the time period 2003-2012. The results of the analysis indicated that three main industries have a quadratic relationship with NO_2, but a negative relationship with PM_{10} and SO_2. The API showed an inverted U-shape curve with the GRP per capita which was the typical type of the EKC.

In a paper entitled “Research on the Relationship of Environmental Pollution and Economic growth in China,” Zhang Jiansheng and Li Qing (2011) investigated the relationship of environmental pollution and economic growth, using the data during the time period 1980-2009 in China. The final results are: industrial wastewater (IWW) and

GDP per capita have an “N” shape relationship with GDP per capita, while industrial gas waste (IGW) and industrial solid waste (ISW) display a “U” shape relationship with GDP per capita. The authors argued that the economic development has been achieved at the cost of environmental degradation since the time of China’s reform and opening-up policy. The authors suggested that China’s government should take measures to deal with the conflict between environment and economic growth to achieve sustainable development.

4. A THEORETICAL MODELOF PRODUCTION AND POLLUTION: THE ENVIRONMENTAL KUZNETS CURVE

It would be common in developed countries, which have already passed the turning point, to support economic growth and avoid environmental regulations. However, early implementation of tight environmental regulation in developing world would be more likely to harm the economy. Here are several reasons whether EKC hypothesis is effective in policy making. First, EKC analysis is typically based on limited set of pollutants so the conclusions made by these analyses cannot be applied to all types of environmental damage. For instance, no clear evidence shows an EKC relationship in the Ecological Footprint, which is a measure of the pressure that man places on the environment, unless energy use is removed from the measure (Caviglia-Harris et al, 2009). Furthermore, EKC relationship is strong when impacts are local. When impacts are global, when income rises, carbon and greenhouse gas emissions increase, even in the developed countries. Second, the supporting evidence has been found less reliable than previously thought (Stern, 2004): EKC’s predictions of the relationship between income and pollution are heavily influenced by the mathematical model adopted

(Millimet et al, 2003). Third, the cost of improving environmental quality and repairing damage after the turning point may possibly be higher than the cost of preventing the damage or undertaking the mitigation earlier. For example, the cost of avoiding the pollution of a waterway is much less than the cost of cleanup after the damage has been done. Fourth, there is evidence showing that similar level of wealth may perform differently under EKC hypothesis (Magnani, 2000).

An economy produces a consumption good from four inputs: capital (*K*), labor (*L*), energy (*E*), and materials (*M*). Following Stokey (1998), we assume that the output of the consumption good at any time *t* is given by the following Cobb-Douglas production function:

(1) $Y(t) = AK(t)^{\alpha}L(t)^{1-\alpha}z(t),$

where $Y(t)$ is the output at time t; A is the total factor productivity a; $K(t)$ is the capital input at time t; $\alpha, 0 < \alpha < 1,$ is a parameter; $L(t)$ is the labor input at time t; and $z(t)$ is an index of environmental degradation at time t.

The index of environmental degradation $z(t)$ is assumed to lie inside the unit interval $[0,1]$, with the interpretation that the higher the value of $z(t)$, the dirtier the production technology and the higher the output of the consumption good. The production function, as specified by (1), embodies the assumption that dirtier technology yields higher output. When $z(t) = 1$, the production technology is the one with the maximum pollutant emissions. When $z(t)$ falls below 1, the environment improves with the introduction of cleaner and more advanced technologies, but the output decreases. When $z(t) = 0$, there are no emissions, but output also falls to 0.

We are not interested in population growth, and thus, shall assume that the population is constant and normalize it to be equal to 1. Under the assumption of constant population, (1) simplifies to

The production function (1) can be expressed under the per capita form as follows:

(2) $$Y(t) = AK(t)^{\alpha} z(t),$$

Although consumption also generates pollution, it will be ignored. The model only consider pollution generated in the production process. More specifically, emissions from production activities are given by

(3) $$x(t) = AK(t)^{\alpha} z(t)^{\beta},$$

where $x(t)$ represents the emissions at time t; and $\beta > 1$ is a parameter.

The instantaneous utility function of the representative consumer at time *t* is

(4) $$u(t) = \frac{C(t)^{1-\sigma} - 1}{1-\sigma} - \frac{B}{\gamma} X(t)^{\gamma},$$

where $u(t)$ denotes the utility of the representative agent; $C(t)$ is the consumption of the representative agent; $\sigma > 0$ denotes the parameter of the Arrow-Pratt measure of relative risk aversion. Also, $X(t)$ is the stock of pollution stock in the economy at time t, and $B > 0$ and $\gamma > 1$ are two parameters, which characterize the disutility from the pollution stock.

The motion of the stock of pollution is governed by the following differential equation:

(5) $$\frac{dX}{dt} = x(t) - \eta X(t)$$

$$= AK(t)^{\alpha} z(t)^{\beta} - \eta X(t),$$

where $\eta > 0$ is a parameter that represents the degree of purification capacity of the environment.

The motion of the stock is governed by the following differential equation:

(6) $\frac{dK}{dt} = AK(t)^{\alpha} z(t) - \delta K(t) - C(t),$

where $0 < \delta < 1$ is the capital depreciation rate.

Under the above setup, a social planner solves the following maximization problem:

Choose a time path for the production technology $t \to z(t), 0 \leq z(t) \leq 1, t \geq 0$, and a time path for the consumption of the representative agent $t \to C(t), t \geq 0$, to maximize

(7) $\int_0^{\infty} e^{-\rho t} \left(\frac{C(t)^{1-\sigma} - 1}{1-\sigma} - \frac{B}{\gamma} X(t)^{\gamma} \right) dt$

subject to

(6) $\frac{dK}{dt} = AK(t)^{\alpha} z(t) - \delta K(t) - C(t),$

(5) $\frac{dX}{dt} = AK(t)^{\alpha} z(t)^{\beta} - \eta X(t),$

(8) $K(0) = K_0, X(0) = X_0$ are given.

In (7), $\rho > 0$ is the social discount rate.

To solve the above maximization problem, first write the Hamiltonian

$$\mathcal{H}(K, X, z, C, \lambda, \mu, t) = e^{\rho t} \left(\frac{C^{1-\sigma} - 1}{1-\sigma} - \frac{B}{\gamma} X^{\gamma} \right) + \lambda(AK^{\alpha} z - \delta K - C)$$

$$+ \mu\left(AK^{\alpha} z^{\beta} - \eta X\right).$$

Let $\overline{z}(t)$ denote the optimal production technology at time *t* and $\overline{C}(t)$ the optimal consumption also at time *t.* The capital stock and the stock of pollution at time *t* under the optimal control $t \to \left(\overline{z}(t), \overline{C}(t)\right), t \geq 0$, are denoted, respectively, by $\overline{K}(t)$ and $\overline{X}(t)$.

Also, let $\lambda(t)$ and $\mu(t)$ denote, respectively, the shadow price of capital and the shadow price of pollution both at time *t* along the optimal trajectory.

The optimal consumption at time *t* satisfies the following first-order condition

(9) $$\frac{\partial \mathcal{H}\left(\overline{K}(t), \overline{X}(t), \overline{z}(t), C, \lambda(t), \mu(t), t\right)}{\partial C} = e^{-\rho t} C^{-\sigma} - \lambda(t) = 0,$$

from which we obtain

(10) $$\overline{C}(t) = \left(e^{\rho t}\lambda(t)\right)^{-\frac{1}{\sigma}}.$$

The following first-order condition characterizes the optimal production technology at time *t.*

(11) $$\frac{\partial \mathcal{H}\left(\overline{K}(t), \overline{X}(t), \overline{z}(t), \overline{C}(t), \lambda(t), \mu(t), t\right)}{\partial z} = \lambda(t) A K^{\alpha} + \mu(t) \beta A K^{\alpha} \overline{z}(t)^{\beta - 1} \leq \ 0,$$

with equality holding if $\overline{z}(t) < 1$.

It is clear from (11) that

(12) $\overline{z}(t) = 1$ if $\lambda(t) + \mu(t)\beta \geq \ 0$.

When $\lambda(t) + \mu(t)\beta < \ 0$, we have

(13) $$\overline{z}(t) = \left(-\frac{\lambda(t)}{\mu(t)\beta}\right)^{\frac{1}{\beta - 1}}.$$

The motion of the shadow price of capital is governed by the following adjoint equation:

(14) $$\frac{d\lambda}{dt} = -\frac{\partial \mathcal{H}\left(\overline{K}(t), \overline{X}(t), \overline{z}(t), \overline{C}(t), \lambda(t), \mu(t), t\right)}{\partial K} = -\lambda(t)\left(\alpha A \overline{K}(t)^{\alpha - 1} \overline{z}(t) - \delta\right)$$
$$-\mu(t)\left(A \alpha A \overline{K}(t)^{\alpha - 1} \overline{z}(t)^{\beta}\right).$$

Letting $\overline{\lambda}(t) = e^{\varrho t}\lambda(t)$ denote the current shadow price of capital at time *t* along the optimal trajectory, we have

(15) $$\frac{1}{\overline{\lambda}(t)} \frac{d\overline{\lambda}}{dt} = \varrho - \left(\alpha A \overline{K}(t)^{\alpha - 1} \overline{z}(t) - \delta\right) - \frac{\mu(t)}{\lambda(t)}\left(\alpha A \overline{K}(t)^{\alpha - 1} \overline{z}(t)^{\beta}\right)$$
$$= \varrho + \delta - \frac{\alpha \overline{Y}(t)}{\overline{K}(t)} - \frac{\mu(t)}{\lambda(t)}\left(\frac{\alpha \overline{Y}(t)}{\overline{K}(t)} \overline{z}(t)^{\beta - 1}\right).$$

When $\bar{z}(t) = 1$, (15) is reduced to

(16) $$\frac{1}{\bar{\lambda}(t)}\frac{d\bar{\lambda}}{dt} = \varrho + \delta - \frac{\alpha\bar{Y}(t)}{\bar{K}(t)}\left(1 + \frac{\mu(t)}{\lambda(t)}\right).$$

When $\bar{z}(t) < 1$, (15) is reduced to

(17) $$\frac{1}{\bar{\lambda}(t)}\frac{d\bar{\lambda}}{dt} = \varrho + \delta - \frac{\alpha\bar{Y}(t)}{\bar{K}(t)}\left(1 + \frac{1}{\beta}\right).$$

The motion of the shadow price of pollution is governed by the following differential equation:

(18) $$\frac{d\mu}{dt} = -\frac{\partial\mathcal{H}\left(\bar{K}(t),\bar{X}(t),\bar{z}(t),\bar{C}(t),\lambda(t),\mu(t),t\right)}{\partial X} = e^{-\varrho t}B\bar{X}(t)^{\gamma-1} + \mu(t)\eta.$$

Letting $\bar{\mu}(t) = e^{\varrho t}\mu(t)$ denote the current shadow price of pollution at time t along the optimal trajectory, we have

(19) $$\frac{1}{\bar{\mu}(t)}\frac{d\bar{\mu}}{dt} = \rho + \eta + \frac{B\bar{X}(t)^{\gamma-1}}{\bar{\mu}(t)}.$$

Suppose that the initial value of capital, K_0, is much smaller than its steady state value. Then at time $t = 0$ the shadow price of capital $\lambda(0)$ is sufficiently larger than the shadow price $\mu(0)$ of pollution, and $\bar{z}(0) = 1$. If t is small, $\bar{z}(t) = 1$, and $Y(t), K(t), x(t)$ all rise as t rises above 0. However, as capital accumulation progresses, $\lambda(t)$ decreases and $\mu(t)$ increases. Eventually, $\mu(t)$ exceeds $\lambda(t)$ and then $z(t) < 1$. After that, $z(t)$ decreases over time, and the EKC shows a downward sloping curve. For a more detailed analysis, we refer the reader to Uchiyama (2016).

In summary, although pollution emissions increase with an increase in production in a country's early stage of economic development, pro-environmental production technology will be introduced, and pollution emissions will decrease after economic development has reached a certain level. Moreover, both the pollution flow and the pollution stock decrease in the convergence to the steady state. Figure 3 depicts the EKC that comes out of the theoretical model of Stokey.

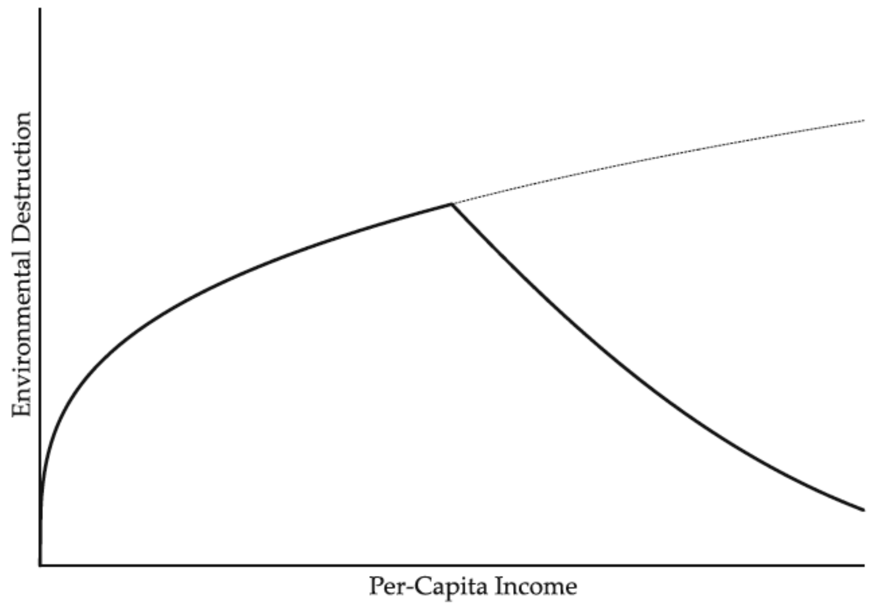

Figure 3.- The Environmental Kuznets curve according to the Stokey model

5. THE ECONOMETRIC MODEL

In most empirical studies, the concentration and emission of pollution are two basic variables used in analysis. Because industrial wastes are the main sources of pollution, we shall choose use industrial wastewater (unit: 10^9t), industrial solid waste (unit:10^4t), and industrial waste gas (unit: $10^4 m^3$) as pollution indicators. In our model, waste gas includes sulfur dioxide and smoke and dust emissions. Also, we use GDP per capita (unit: RMB) to reflect economic growth. The data, which span the years from 1995 to 2013, are from the "Statistical Yearbook of Sichuan Province"[2].

In order to avoid the problems of multi-collinearity and heteroscedasticity, we use the log form of each variable. Furthermore, it is much likely that we get stationary series

[2] Source: http://www.sc.stats.gov.cn/tjcbw/tjnj/

after transformation with the characteristics remain unchanged. We use LNIWW to denote industrial wastewater, LNISW to represent industrial solid waste, LNIGW to represent industrial gas waste, and LNGDP to represent GDP per capita, respectively. The data analysis is carried out using Eviews6.0.

The econometric equation we estimate is

$$GDP = \beta_0 + \beta_1 ISW + \beta_2 IGW + \beta_3 IWW + \varepsilon,$$

where ISW represents industrial solid waste (unit: $10^4 t$); IGW represents industrial gas waste (unit: $10^4 m^3$); and IWW represents industrial wastewater (unit: 10^9t).

6. THE RESULTS

6.1. *The Unit Root Test*

Prior to the co-integration test for a relationship between environmental pollution and economic growth, we conduct the unit root test for the stability of the time series variables. The results are presented in Table 1.

Table 1
Results of unit roots test

Variables	ADF test data	Test type(c,t,p)	5% critical value	Conclusions
LNIWW	-2.596334	C,T,1	-3.039621	UNSTABLE
DLNIWW	-6.63674	c,t,2	-3.081002	STABLE
LNISW	-2.429445	C,T,0	-3.051963	UNSTABLE
DLNISW	-5.376162	c,t,1	-3.065585	STABLE
LNIGW	-1.429445	C,T,0	-3.051963	UNSTABLE
DLNIGW	-4.186637	c,t,1	-3.065585	STABLE
LNGDP	-1.959071	C,T,1	-3.039621	UNSTABLE
DLNGDP	-6.695637	c,t,2	-3.081002	STABLE

Source: author's own calculations.
Notes: c means intercept, t means trend term, p means hysteresis orders which is determined by SIC information principles, D means first order difference.

At the plain level, we cannot reject the null hypothesis that the time series for the four variables are stable, i.e., none of them are stable. As a result, we take the first order difference, according to the Table 1, all of the variables reject the null hypothesis under 5% significant level, which means they are stable under 5% significant level. After taking the first order difference and we can then carry out the do co-integration.

The results of the co-integration test are presented in Table 2.

Table 2
Result of the co-integration test

Variables included	Trace statistics	5% critical value	Maximum eigenvalues	5% critical value
LNGDP & LNIGW	16.42986	15.49471	16.13027	14.26460
	4.299581	3.841466	4.299581	3.841466
LNGDP & LNISW	18.77500	15.49471	18.58667	14.26460
	4.188329	3.841466	4.188329	3.841466
LNGDP & LN IWW	17.12099	15.4971	17.64794	14.26460
	5.473054	3.841466	5.473054	3.841466

Source: author's own calculation.

From table 2, it is easy to find that there exists co-integration relationships between LNIWW, LNISW, LNIGW and LNGDP, which means that the growth of GDP contributes to the decline of industrial waste water, industrial solid waste and industrial gas waste.

6.2. *The Environmental Kuznets Curve Analysis*

This paper carries out a regression on the variables industrial waste water, industrial gas waste, industrial solid waste, and GDP per capita. There are two basic models: one is time series and the other is panel data. In this paper, we use the time series model, which was proposed by Grossman and Krueger (1995). The equation to be estimated has the following functional form:

$$y_t = \beta_0 + \beta_1 x_t + \beta_2 x_t^2 + \beta_3 x_t^3 + \varepsilon_t,$$

where y_t represents pollution emission indicators, and x_t represents GDP per capita.

Depending on the signs of the coefficients on the RHS of the above equation, one of the following situations might arise.

- When $\beta_1 = \beta_2 = \beta_3 = 0$, the equation exhibits a straight line, i.e. economic growth has no impact on environment;
- When $\beta_1 > 0, \beta_2 = \beta_3 > 0$, the equation exhibits monotonic increase, i.e. environment deteriorates with economic growth;
- When $\beta_1 < 0, \beta_2 = \beta_3 > 0$, the equation exhibits monotonic increase, i.e. environment improves with economic growth;
- When $\beta_1 > 0, \beta_2 > 0, \beta_3 > 0$, the equation exhibits an "N" shape curve, i.e. environment firstly deteriorates, and gradually improves and then deteriorates with economic growth;
- When $\beta_1 < 0, \beta_2 > 0, \beta_3 < 0$, the equation exhibits a inverted "N" shape curve, i.e. environment firstly improves, and gradually deteriorates and then improves with economic growth;
- When $\beta_1 > 0, \beta_2 < 0, \beta_3 = 0$, the equation exhibits a inverted "U" shape curve, i.e. the typical EKC, environment deteriorates before improves with economic growth;

- When $\beta_1 < 0, \beta_2 < 0, \beta_3 = 0$, the equation exhibits a “U” shape curve, i.e. environment improves before deteriorates with economic growth;
- When $\beta_1 \neq 0, \beta_2 = \beta_3 = 0$, the equation exhibits linear relationship.

Table 3 presents the estimation results for the above equation.

Table 3
Result of EKC model

Pollution emission index	β_0	β_1	β_2	β_3
LNIGW	*-2.984536 (0.1267)*	*3.456722 (0.0112)*	*-0.991267 (0.4120)*	*2.001231 (0.0612)*
LNISW	*-3.564394 (0.0348)*	*6.823411 (0.0034)*	*-1.762322 (0.0003)*	*0.761133 (0.0137)*
LNIWW	*-4.795647 (0.0955)*	*2.110036 (0.0423)*	*-1.336168 (0.0046)*	*1.440015 (0.0069)*

Source: author’s own calculation.

As can be seen from Table 3, at 10% level of significance, $\beta_1, \beta_2, \beta_3$ are significantly different from zero with $\beta_1 > 0, \beta_2 < 0, \beta_3 > 0$; we know that LNGDP and LNIWW exhibits an “N” relationship. At 5% significant level, $\beta_1, \beta_2, \beta_3$ are significantly different from zero and $\beta_1 > 0, \beta_2 < 0, \beta_3 > 0$; we know that LNGDP and LNISW exhibits an “N” relationship.

Also, the p-value is greater than 0.1 for some of the coefficients, and we cannot conclude that the coefficients are significantly different from zero: there is no linear or non-linear relationship between LNGDP and LNISW.

To summarize the analysis, LN GDP and LNIWW exhibits an “N” relationship instead of inverted “U” relationship, LNGDP and LNISW exhibits an “N” relationship instead of inverted “U” relationship, LNGDP and LNIGW exhibits no linear or non-linear relationship which is different from the conclusions made by other authors.

6.3. *The Granger Causality Test*

According to the co-integration test, there exist co-integration relationships between LNIWW, LNISW, LNIGW and LNGDP, and this means the growth of GDP contributes to the decline of industrial wastewater, industrial solid waste, and industrial gas waste. However, we do not know whether income changes lead to pollution emissions changes or whether pollution emissions changes result in income changes. We conduct a Granger causality test to solve this problem. The results of the Granger causality test are presented in Table 4.

Table 4
Result of Granger test

Null hypothesis	Observations	F-statistics	Probability	Conclusion
Granger cause of LNIWW or LNGDP	19	2.657433	0.657455	accept
Granger cause of LNGDP or LNIWW	19	0.657866	0.710990	reject
Granger cause of LNIGW or LNGDP	19	4.697853	0.343545	accept
Granger cause of LNGDP or LNIGW	19	1.562342	0.223370	accept
Granger cause of LNISW or LNGDP	19	0.997112	0.170064	accept
Granger cause of LNGDP or LNISW	19	0.545655	0.768674	reject

Source: author's own calculation.

As can be seen from Table 4, Granger causality only exists between LNGDP and LNIWW, LNISW and LNGDP, but no Granger causality between LNIGW and LNGDP. Economically speaking, GDP per capita makes a large contribution to the industrial wastewater and industrial solid waste, but not to industrial gas waste. Furthermore, changes in environmental pollution make no contribution to the economic growth.

7. CONCLUSION

The goal of this paper is to determine whether the industrial pollution – industrial gas waste, industrial solid waste and industrial wastewater – will affect economic growth. The results of the paper show that the increase in industrial solid waste and industrial wastewater would have a negative impact on economic development. Gas waste, on the other hand, has a positive impact on economic development. However, this last result does not necessarily mean we should produce more gas waste thinking that this would have a positive effect on economic growth. In reality, the air quality in Sichuan province is becoming worse and worse, and this problem has attracted government's attention to release new policies in order to improve the environment condition. The first action to undertake is to phase out and shut down the business activities that are technology-backward and that are causing heavy pollution. In 2001 and 2004, the government shut down 30 thousand factories and companies that heavily consume resources and energy. Efforts have been made to deal with the heavily polluting industries such as: steel, cement, electricity, aluminum, and iron. The government also suspended some projects that were not in accordance with the related industry policies. The second action is to encourage recycling. Factories should make the best use of the resources and control the waste generated in the process of production. The government should consider an overall planning of the development of industry and farming, production and consumption, urban and rural.

Appendix A
Data Sources

YEAR	IWW	ISW	IGW	GDP
1995	19.2	4011	210.9	2443.21
1996	15.1	4323.8	194.4	2871.65
1997	10.7	4988.09	129.6	3241.47
1998	10.3	5284.9	285.5	3474.09
1999	9.5	5011.5	174.5	3649.12
2000	11.7	5832.44	235.3	3928.2
2001	11.5	6664.83	224	4293.49
2002	11.8	6983.54	234.1	4275.01
2003	12	7290.76	226.1	5333.09
2004	11.92	7811.08	229.86	6379.63
2005	12.3	8099.89	215.9	7385.1
2006	11.5	9122.34	196.6	8690.24
2007	11.5	9651.3	154.5	10562.39
2008	10.9	9236.9	132.79	12601.23
2009	10.7	10672.12	125.57	14151.28
2010	9.34	11239.2	133.87	17185.48
2011	8.04	12684.47	118.48	21026.28
2012	7	13187.3	106.18	23872.8
2013	6.48	14006.62	104.24	26392.07

Notes: Data is from "Statistical Yearbook of Sichuan Province". (*http://www.sc.stats.gov.cn/tjcbw/tjnj/*)

Appendix B
OLS test result

Dependent Variable: GDP
Method: Least Squares
Date: 10/02/17 Time: 14:52
Sample: 1995 2013
Included observations: 19

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1442.774	5230.759	6.275825	0.0067
ISW	-2.954359	1.933562	-2.553331	0.0230
IGW	81.52811	104.4573	3.838063	0.0049
IWW	-12.19064	22.30734	-3.363557	0.0216

R-squared	0.953979	Mean dependent var	9566.096
Adjusted R-squared	0.940831	S.D. dependent var	7591.177
S.E. of regression	1846.534	Akaike info criterion	18.10094
Sum squared resid	47735637	Schwarz criterion	18.34948
Log likelihood	-166.9590	Hannan-Quinn criter.	18.14300
F-statistic	72.55294	Durbin-Watson stat	2.043077
Prob(F-statistic)	0.000000		

REFERENCES

Arrow K. Bolin B., Costanza R., Dasgupta P., Folke C., Holling C.S., Jansson B., Levin S., Mäler K., Perrings C. and D. Pimentel,1996, "Economic growth, carrying capacity, and the environment." *Environment and Development Economics,* 1, 104-110.

Beckerman W., 1992, "Economic growth and the environment: whose growth? Whose environment", *World Development*, (20):481-496.

Berman E. and L. Bui, 1998, "Environmental Regulation and Labor Demand: Evidence from the
South Coast Air Basin", National Bureau of Economic Research Working Paper No. 6776.

Bimonte S., 2009, "Growth and environmental quality: Testing the double convergence hypothesis", *Ecological Economics*, 68, 2406–241.

Blazejczak J., Braun F. and D. Edler, 2009, "Global Demand for Environmental Goods and Services on the Rise: Good Growth Opportunities for German Suppliers", German Institute for Economic Research, 5, 20, 138-145.

Boulding K. E., 1966, "The Economics of the Coming Spaceship Earth", Environmental Quality in a Growing Economy, ed., H. Jarrett, Baltimore, MD: John Hopkins Press.

Carraro C., De Cian E. and M. Tavoni, 2009, "Human Capital Formation and Global Warming
Mitigation: Evidence from an Integrated Assessment Model", CESIFO WP 2874.

Caviglia-Harris J., Chambers L., Dustin K. and R. James, 2009, "Taking the "U" out of Kuznets: A comprehensive analysis of the EKC and environmental degradation", Ecological Economics, Elsevier, 68(4), 1149-1159.

Choudhury K. and L. Jansen, 1997, Terminology for integrated resources planning and management. Rome, FAO, Soils Resources Management and Conservation, 59.

Cole M. A., 2004, "The pollution haven hypothesis and the environmental Kuznets Curve: Examining the linkages", *Ecological Economics*, 48(3), 71-81.

Coondoo D. and Dinda S., 2002, "Causality between income and emissions: a country group-specific econometric analysis", *Ecological Economics*, 40(3), 351-367.

Davidson C., 2000, "Economic growth and the environment: alternatives to the limits paradigm", BioScience 50:433–440.

Davis G. A., 1995, "Learning to love the Dutch disease: Evidence from the mineral economies”, *World Development*, 23(10), 1765–1779.

Day K. M. and Graften R. Q., 2003, “Growth and the environment in Canada: An empirical analysis, Canadian Journal of Agricultural Economics”, 51(3), 197-216.

Dietz S., 2000, “Does an environmental Kuznets curve exist for biodiversity?” Institut für Wirtschaftsforschung, Eidgenössische Technische Hochschule Zürich.

Dutt K., 2009, “Governance, institutions and the environment-income relationship: a cross-country study”, Environment, Development and Sustainability, 11:4, 705-723.

Easterlin R. A., 1974, “Does economic growth improve the human lot?”, Nations and Households in Economic Growth, Academic Press.

Eatherley D. and S. Slater, 2009, “Competitiveness Improvements Potentially Available from Resource Efficiency Savings”, report for Defra.

Ekins P., 2000, “Economic Growth and Environmental Sustainability: The Prospects for Green Growth”, Routledge, London.

Frontier Economics, 2009, “Alternative policies for promoting low carbon innovation.” Report for Department of Energy and Climate Change.

George E. Halkos, 2003, “Environmental Kuznets Curve for sulfur: evidence using GMM estimation and random coefficient panel data models”, *Environmental and development economics* 8 (4), 581-601.

Gray W. B. and R. J. Shadbegian, 1998, “Environmental Regulation, Investment Timing, and Technology Choice”, *Journal of Industrial Economics* 46:235-256.

Grossman G. and Krueger A., 1992, “Environmental impacts of a North American free trade agreement”, Garber P., The Mexico-US Free Trade Agreement, Cambridge, MA: M ⅡPress.

Grossman G. and Krueger A., 1995, “Economic Growth and the Environment”, *Quarterly Journal of Economic*, 110(2), 353-372.

Harris J M. and N. R. Goodwin, 2003, “Reconciling Growth and Environment”, GDAE Working Papers 03-03, GDAE, Tufts University.

Innovas, 2009. “Low Carbon and Environmental Goods and Services: an industry analysis.” Report for BERR.

Jaffe A. B., Newell R. G. and R. N. Stavins, 2000, “Technological Change and the Environment”, WP7970, National Bureau of Economic Research.

Jaffe A. B. and K. Palmer, 1997, “Environmental Regulation And Innovation: A Panel Data Study,” *The Review of Economics and Statistics*, MIT Press, 79(4), 610-619.

Jaffe A. B., Peterson S. R., Potney, P.R. and R. N. Stavins, 1995, “Environmental Regulation and the competitiveness of US Manufacturing: What does the evidence tell us?”, *Journal of Economic Literature*, 23, 132-163.

Jorgenson D. W. and P. J. Wilcoxen, 1990, “Environmental Regulation and U.S. Economic Growth”, The RAND *Journal of Economics*, 21-2, 314-340.

Kuznets S., 1934, "National Income, 1929-1932". 73rd US Congress, 2nd session, Senate document no. 124, 7.

Kuznets S., 1955, “Economic growth and income inequality,” *American Economic Review*, 49.l-28.

Lewis W. A., 1954, “Economic Development with Unlimited Supply of Labour”, The Manchester School, 22, 2:139-91.

Liang J. and McKitrick R., 2002, “Income growth and air quality in Toronto: 1973-1997”, Mimeo, University of Guelph, Economics Department.

Liu G., 2006, “A causality analysis on GDP and air emissions in Norway”, Discussion Papers, Statistics Norway, No.447.

Liu L., 2005, “The Environmental Kuznets Curve of Guangdong Province”, Research of Environmental Sciences, 18(6), 6-11.

Magnani E., 2000, “The Environmental Kuznets Curve, environmental protection policy and income distribution”, *Ecological Economics* 32, 431–443.

Meyer S. M., 1992, “Environmentalism and economic prosperity: testing the environmental impact hypothesis, MIT Mimeo.

Millennium Ecosystem Assessment, 2005, “Ecosystems and Human Wellbeing: Synthesis.” Island Press, Washington DC.

Omisakin A. O., 2009, “Economic growth and environmental quality in Nigeria: Does environmental Kuznets Curve hypothesis hold?”, *Environmental Research Journal*, 3(1),14-18.

Palmer K., W. E. Oates and P.R. Portney, 1995, “Tightening Environmental Standards:The Benefit-Cost or the No-Cost Paradigm?” *Journal of Economic Perspectives* 9:119-132.

Panayotou T., 2000, “Economic Growth and the Environment.” CID Working Papers 56, Center for International Development at Harvard University.

Peng L., Tong X. and Shen Y., 2008, “Quantitative process of environment and economic progress in Shanghai”, *China Population Resources And Environment*, 18(3),186-194.

Peng S. and Bao Q., 2006, “Economic growth and environmental pollution: an empirical test for the environmental Kuznets Curve hypothesis in china”, *Research On Financial And Economic Issues*, (8):3-17.

Porter M. E. and C. van der Linde, 1995, “Towards a New Conception of the Environmental Competitiveness Relationship”, *Journal of Economic Perspectives* 9, 97-118.

Ranjan R. and J. Shortle, 2007, “The environmental Kuznets curve when the environment exhibits hysteresis.” Ecological Economics, Elsevier, 64(1), 204-215.

Selden T. M. and D. Song, 1994, “Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions?” *Journal of Environmental Economics and Management*, Elsevier, 27(2), 147-162.

Shen M. and Xv Y., 2000, “A new type of Kuznets Curve: the relationship between economic growth and environment change”, *Zhejiang Social Sciences*, (7),53-57.

SQW, 2007, “Exploring the relationship between environmental regulation and competitiveness – Literature Review. Final Report to the Department for Environment Food and Rural Affairs”, Defra.

Stern D. I., Michael S. C. and Edward B. B, 1996, “Economic growth and environmental degradation: The environmental Kuznets Curve and sustainable development”, *World Development*, 24(7):1151-1160.

Stokey, N.L, 1998, “Are there limits to growth?”, *International Economic Review*, 39, 1-31.

Turner R. K., Morse-Jones S., and B. Fisher, 2007, “Perspectives on the ‘Environmental Limits’ concept: A report to the Department for the Environment, Food and Rural Affairs”, CSERGE, Norwich.

Tim Everett, Mallika Ishwaran, Gian Paolo Ansaloni and Alex Rubin, 2010, “Economic Growth and the Environment”.

Uchiyama, 2016, “Environmental Kuznets curve Hypothesis and Carbon Dioxide Emissions”, 8(63), p.6.

Wang Y., Cui X., and Chen W., 2006, “Empirical research on the relationship between economic growth and environmental degradation in Nanjing city" [J]. *Resources and Environment in the Yangtze Basin*, 15(2), 142-146.

Wang Z., Wen Z.,Yan F., et al., 2007, "Verifying the environmental Kuznets Curve hypothesis and its conditions in Beijing", *China Population Resources And Environment*, 17(2), 40-47.

World Bank, 1992, *World Development Report* 1992: "Development and the Environment ", Washington, DC: The World Bank.

Wu Y. and Dong S., 2002, "Evaluating environmental policy of Beijing", *Urban Environment & Urban Ecology*, 15(2), 4-6.

Yang K., Ye M. and XVQ., 2003, "Environmental Kuznets characteristics of municipal solid waste growth in Shanghai city, Geographical Research", 22(1), 60-66.

Zhang B., Bi J., Ge J., et al., 2008, "Empirical study of environmental Kuznets curve in south Jiangsu, Economic Geography", 28(3), 376-379, 424.