LUND UNIVERSITY
School of Economics and Management

Master programme in Economic Growth, Innovation and Spatial Dynamics

An Empirical Research on Relationship between Economic Growth and Atmospheric Pollution in China– Based on the Panel Data Analysis Approach

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EKHR71
Master thesis, first year (15 credits ECTS)
June 2013
Supervisor: Astrid Kander
Examiner: Håkan Lobell

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Content

1. Introduction

Will sustained economic growth cause greater damage to regional, national and even global environment? Or can environmental quality be beneficial from the increase of income and wealth? Based on economic history of developed countries, most of them experienced the development stage where economic growth caused the degradation of environment. Obviously, answers to these questions are important for developing countries to choose the appropriate development strategy.

The topic of economic growth and environmental protection is always heated in academic circles. The research on the relationship between economic growth and environmental quality is a logic expansion of the debate about the impact of economic growth on environment in economics in the last five decades. On one hand environmental pollution is caused by irrational economic activities, on the other hand only when economy develops to a certain level can the environment problem be solved. In 1960s, many scholars analyzed meaning of economic growth to the environment based on the conservation of mass principal. Output growth in the economic system must lead to the increasing use of natural environment, and at the same time the volume of waste discharge is increasing (Boulding 1966). In 1971, the Rome Club pointed out: economic growth is not sustainable due to the exhaustibility of important resources and the limited capacity of environment to absorb waste. Other scholars disagree with this opinion because under the market mechanism, the increasing price of scare resources will encourage people to use alternative resources. As a result, the limits of growth can be avoided. Hence, the result of the debate helped researchers turn to studying environmental pollution problems from exhausting resources.

In the last decade of 20th century, a series of contaminations, such as carbon dioxide (CO_2), nitrogen oxides (NO_X), sulphur dioxide (SO_2), methane (CH_4), and Freon (CFCs), caused serious environmental consequences. This aroused people's concerns and discussions about economic growth and environment. Many environmental problems happened due to many factors (external diseconomy, regional development strategy and so on), therefore market mechanism only can solve limited problems. However, EKC (Environment Kuznets Curve) provides an alternative solution: the increase of per capita income will improve environmental quality at last –with the increase of income, the pollution level increases at low income level, but pollution finally reduces at high income level. Environmental Kuznets Curve is the Grossman and Kruger's finding when they analyzing the possible effects of NAFTA on environment. The public were worried that free trade policies and FDI may worsen environmental problems in Mexico and lower the standards of environmental regulation in the United States. For testing this point of view, Grossman and Krueger (1991) used simplified model to do the first empirical research on the relationship between economic growth and environmental quality. They found that the relationship can be well described by inverted U shape and economic growth tends to reduce environmental pollution when a country's per capita GDP reaches to $4000-$5000 (1985 price). At that time, this income level is just consistent with Mexico's per capita income level.

Beyond doubt, Grossman and Krueger's analysis and finding is of great importance. If EKC really exists, the solution to the environmental problems should rely on economic growth. Because when per capita income or wealth surpasses the turning point, its increase will lead to the improvement of environmental quality. This means promoting economic growth should be primary policy objective of the international community. After Grossman and Krueger's finding, many empirical researches show that most environmental indicators have an inverted U shape relation with per capita income (Shafik 1994, Selden & Song 1994, etc). However, many scholars found different results, for instance, the relationship between economic growth and environmental pollution may be N shape (Friedl & Getzner 2003).

Environmental Kuznets Curve only describes an objective phenomenon, but not an inevitable rule. Even if it really exists, we should be careful when interpreter and apply results. In fact, many empirical researches are based on panel data approach due to lack of long-term time series data. However, this method may be misleading for the reason that environmental degradation in developing countries appears to be on the rise and environmental pollution in developed countries shows on downward trend. For this reason, EKC may reflect the split joint of the two trends rather than the trajectory of a country's environmental change (Borghese 1999). In this research, a panel data method is implemented to analyze the relationship between economic growth and environmental quality of China.

Environmental pollution is mainly produced in industrialization and urban evolution process. The current environmental pollution issue that the globe face exists in China and it is quite serious. From 1960s onward, as environmental pollution emerges and intensifies as well as the shock of energy crisis, people are increasingly paying attention to the interrelationship between environment and economic growth. However, as one of the most compelling countries in terms of economic development, China has not a good performance in environmental protection. As we all know, fresh air is essential to life. People have inadequate understanding to the harm of air pollution. Once there is excess industrial waste gas in the air, the air will become toxic gas, which will threat health and induce many respiratory system diseases. For instance, 'London smog event' led to a tragedy because the air contained a lot of sulfur dioxide. The event has been one part of history, but its warning is of far-reaching significance. For China, China's headlong growth is evident across the country at the cost of environmental pollution in the cities (e.g. air pollution). That is main reason for children's high incidence rate of respiratory disease in big cities. Compared to environmental performance, China's economic development shocks the whole world. Since the reform and opening up, the economy in China has experienced a rapid development stage. Inevitably, this kind industrial production caused enormous pressure on the environment during this period of rapid economic growth. The government hopes to develop Chinese economy in a sustainable way and to build a conservation-conscious society. It is the government's responsibility to solve the conflict between the economic development and environmental protection. The result of this research will be helpful for policy-makers to make certain development strategy.

Judging from the research on Environmental Kuznets Curve, it can be seen that, in general, most researches support the existence of EKC and a few negative the EKC. Further, the relationship between economic growth and environmental pollution can be well characterized by inverted U shape in a long term. But in the short term, it may appear all sorts of wave, such a 'U', 'N' or other shapes. Besides, most researches regarding EKC use international panel data. We are not sure whether EKC is suitable for every country, especially for developing countries. In a word, empirical analysis of China will be contributed to existing EKC research.

What is the relationship between economic growth and atmospheric pollution in China? Can the Environment Kuznets Curve describe this relationship? The aim of this thesis is to test the existence of Environmental Kuznets Curve in China which is a developing country. Although various pollutants were studied in EKC literature history, three atmospheric pollutants are mainly tested in this research including industrial sulphur dioxide, industrial dust and industrial soot. Compared with other empirical studies of China on EKC, this research has relatively longer time period and more objects, with 20 years from 1991 to 2010 and 29 provinces respectively. This means that for each pollutant 580 observations are available for the study. In the next part, previous research on Environmental Kuznets Curve including research history and critique will be presented. Then the following part is about Chinese characterized facts of environmental pollution and economic growth. The last part is about data, methods and results. Based on provincial environmental data (sulfur dioxide, industrial soot, and industrial dust) and economic data (GDP per capita), panel approach will be applied to study the possible relationship.

2. Literature Review

Since 1990s, EKC research has been heated topic for international academia and the EKC hypothesis has raised debates in academic world. However, the evolution path of environmental quality along with economic development which is revealed by Environmental Kuznets Curve is accepted by majority of scholars. There are two important aspects of current EKC research, one is empirical test which shows whether EKC exists or not by using different pollutants in different areas, another is to study the forming reasons and mechanism of EKC. Following part is the literature review of Environment Kuznets Curve.

In the early 1970s, the famous Club of Rome put forward the idea of "limits to the growth" in its book. They thought that economic growth cannot be sustainable due to the limits of natural resources, and economic growth should be slowed down in order to achieve the purpose of the protection of the environment resources (Meadows et al. 1972). However, other scholars oppugned the above view that economic development will inevitably lead to the deterioration of the environment. For example, Beckerman (1992) considered promoting economic development as an effective means for protection of the environment resources. When Kuznets did research on income gaps, he found that income gap increase first, and then decrease as economies grow. The relation between the two variables is known as "Kuznets curve". With the help of Kuznets Curve, these scholars pointed out that there may have the inverted U curve relationship between environmental quality and economic development, that is, the increase of economic growth and per capita income will lead to a drop in the equality of the environment in the early stages of economic development, however, once the economic development beyond a critical value point, the improvement of per capita income will help to reduce environmental pollution and to improve environment quality. Inspired by this point of view, a large number of scholars use countries' cross-section data, time series data or international panel data to do wide research on whether there is Environmental Kuznets curve.

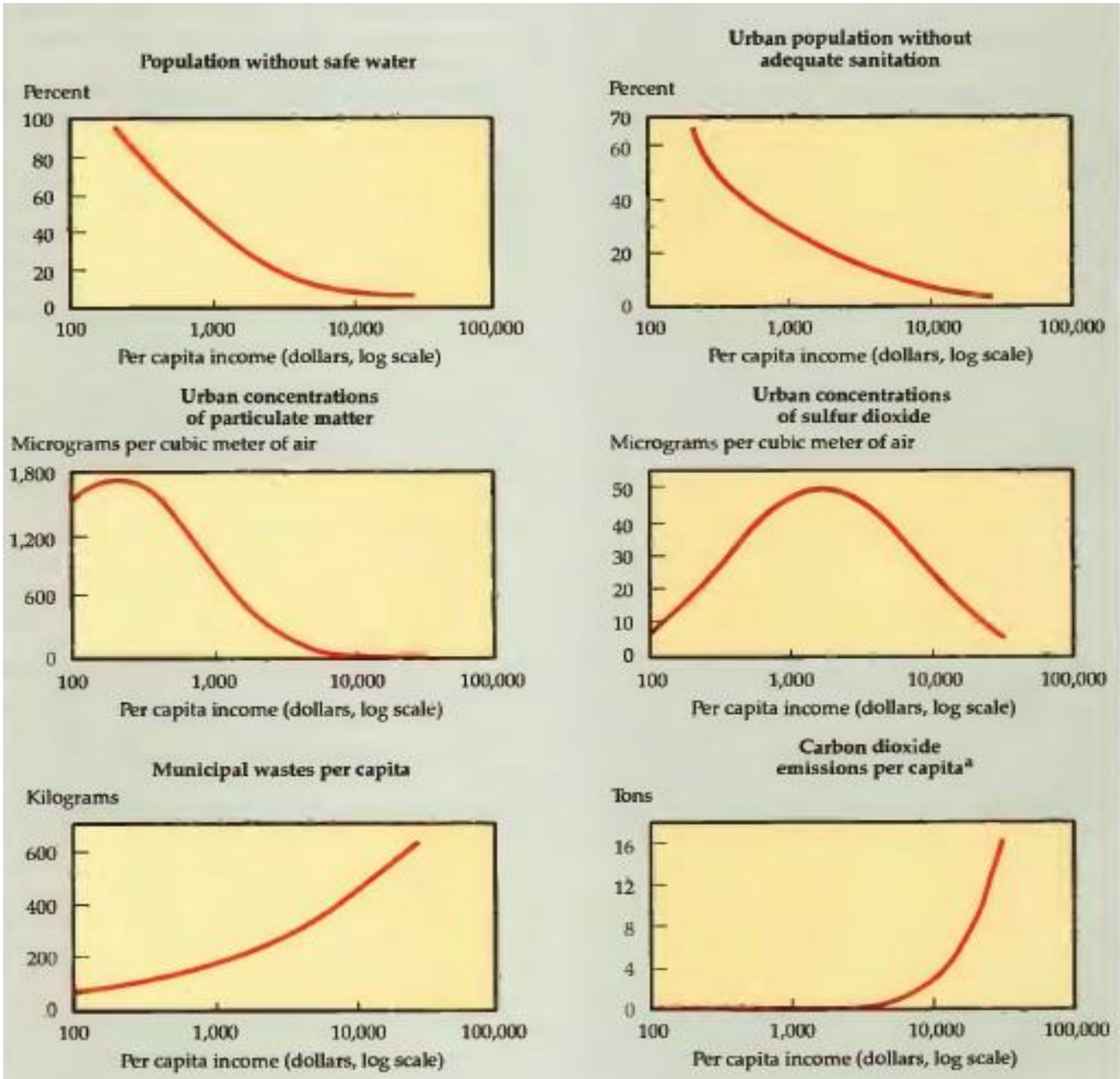
Grossman and Krueger (1991) first did empirical research for the first time on the existence of inverted U-relationship between environment and income, when they were analyzing the environmental effects of the North American free trade agreement (NAFTA). In the far-reaching article, Grossman and Kruger used functions of economic development (economic scale, economic structure, technology) to explain the existence of EKC: Economic development means there are a larger-scale economic activities and a bigger resources demand, so it has negative scale effects. But at the same time, it will reduce pollution emission and improve the environment quality by positive technological progress (such as the use of new technologies) and structural effects (such as the upgrading of industrial structure and optimization).

After Grossman and Kruger, a large number of scholars (Stern, 1998; Panayotou, 2000; Dinda, 2004; etc) did further tests of the relationship between environment and income. However, the conclusion is not the same because of different choices of types of data, pollutant, country and approach. For example, In terms of the choice of environment quality indexes, while many scholars select pollution emissions the others choose pollutants concentration or integrated index.

Through the analysis of air quality-income relationship which is based on data from GEMS, Krueger (1991) found that SO_2-per capita GDP and smoke-per capita GDP showed inverted U relationship and air particulate matter increased as per capita GDP grew. Shafik (1994) also found that with the rise of per capita income, SPM and

SO_2 increased first and then decreased, however, solid waste and carbon emissions continued to worsen. Selden and Song (1994) studied the emissions of four kinds air pollution (SO2, CO_2, NO_2, SPM), and found all of them have inverted U relationship with per capita income. The World Bank popularized EKC theme in World Development Report 1992 and according to World Development Report (1992), there are three relationships between economic growth and environmental degradation (see figure 1). Some environmental indicators, such as the lack of safe water and urban sanitation, decrease with increasing income which indicates that economic growth can improve environmental quality. Many indicators like carbon dioxide emission, solid wastes and dissolved oxygen in rivers grow as income increases, showing that environmental quality degrade with economic growth. Other environmental indicators (such as sulfur dioxide and nitrous oxide emissions have an inverted U-relation with income, implying that environmental quality worsens in the first development stage and gets to the highest level, then environmental degradation becomes better when income surpasses the turning point (Shafic and Bandyopadhyay 1992).

Figure.1. Environmental indicator at different country income levels



Source: Shafic and Bandyopadhyay (1992), World Development Report (1992)

Other empirical researches are linked with water, air, heavy metal and forest and most environmental quality indicators have inverted U-relation with economic indicators. Meanwhile, more scholars tried to figure out the effects of certain factor on environmental quality. Cole (2004) found that the existence of stages of environmental improvement was due to the increasing needs of environmental laws, investments of environmental protection technology, free trade and so on. Bruuyn (1997) calculated the effects of economic scale, industrial structure and pollutant intensity on Holland's and West Germany's SO_2 emission. Hilton etc (1998) did research to analyze the impacts of economic scale and technology on gasoline-lead levels in many countries. Viguier (1999) counted the effects of quality and structure of oil, industrial structure, energy structure and productivity in Russia, Poland, Hungry, France, USA, and UK on many pollutant discharges. Selden etc (1999) and Stern (2002) figured out the influence of industrial structure, economic scale, energy structure, productivity and environmental technology on SO2 emissions of United States and the whole world respectively. Hamilton et al. (2002) and Zhang (2000) made the calculation of effects of fossil energy's share of total energy consumption, productivity, economic scale, etc on OECD countries' and China's CO2 emission. Another scholar calculated the effects of economic scale, industrial structure, technology and trade on global CO2 emission of United States and the whole world respectively. Hamilton et al. (2002) and Zhang (2000) made the calculation of effects of fossil energy's share of total energy consumption, productivity, economic scale, etc on OECD countries' and China's CO2 emission. Another scholar (Antweiler 2001) calculated the effects of economic scale, industrial structure, technology and trade on global CO2 emission.

As the fast development of Chinese economy, environmental problem is becoming more and more severe. Many scholars studied detailed economic factors which degrade environment quality. For example, Wang et al. (1999), cited in Yu, Qi & Tian (2006), and Ling (2001) calculated economic scale, economic structure, etc's effects on national and Nanjing's discharge of three waste (waste gas, waste water, and waste residues). Chen et al. (2004), Li et al. (2005), Sun (2006), Huang (2005) counted the effects of economic scale on many pollutants' emission of Hunan, Hebei, Qinghai, Shenzhen respectively. Yang (2005) studied the relationship between environmental index (SO2, COD, C_d, etc) and economic factors (trade, FDI, economic scale).

With the development of EKC research, researchers started to study Environmental Kuznets Curve in one country or one region. Using provincial panel data of Malaysia to look for relationship between environmental pollution and economic growth, Vincent (1997) found that features for proving the inverted U relationship between Malaysia's economic growth and seven pollution indicators were not obvious. Based on German historical data of economic growth and environmental pollution, Egli (2001) found that the relationship between only few pollutants (such as NOx and NH3) and per capital GDP can be described as an inverted U-curve, but not for other pollutants (SO2, CO, CO2, CH4, etc).

The EKC research in China started in late 20th century. Using simplified model to estimate EKC of industrial wastewater, industrial waste gas and solid industrial wastes and Based on data from 1986 to 2003, Ma and Li (2006) summarized a conclusion that Chinese environmental pollution will not decrease automatically with the development of economy by adopting time series, stationarity and cointegration method. Using data of environmental statistic in the period 1985-1995, Zhang et al. (1999), cited in Zhou et al. (2010), made a conclusion that the relationship between China's economic development and environmental pollution level shows weaker EKC characteristics. To examine the EKC relationship between per capita income and six kinds of pollution indicators, Peng and Bao (2006 a) used panel data on China's thirty provinces during 1996-2002 to research the relationship between pollution and economic growth, and they found that the results are highly sensitive to different pollution indicators, functional forms and econometrics methods. Then five control variables were added and the result shows that inverted U-curve can describe the relationship for two pollutants (industrial waste water and industrial sulphur dioxide). Besides, they found that social changes such as population density, trade openness, environmental policies, technological progress and industrial structure change have effects on the shape of Environmental Kuznets Curve (Peng and Bao 2006a). Based on nonparametric approach, Fu (2008) analyzed the shape, turning point, affecting factors of Environmental Kuznets Curve and made suggestion to improve industrial structure according to the dynamic changing characteristics of EKC.

Many scholars in China did provincial EKC research (see Table.1.), for example Wu, Dong and Song (2002) used time series approach to analyze the relationship between Beijing's economic growth and environmental quality and the result proves the inverted U shape. However, applying panel data method, Li and Wang (2007) did not come to such conclusion when they studied the relationship between three pollutants and economic growth. Based on Guangdong's regional data from 1985 to 2003, the relationships between three industrial wastes and per capital GDP do not appear as inverted U-shape, but N-shape (Zhang J. & Zhang Y.J. 2006). Chen and Liu (2004) used air quality data and income data of Shanghai from 1990 to 2001 to examine the simplified form of the relationship between environmental quality and per capita income and they found that the case of Shanghai demonstrates that the hypothesis of EKC holds true for three of the four indicators (TSP, NOX, CO). In addition, the turning points vary for different pollutants (Chen and Liu 2004). Based on Jiangsu's data in the period 1986-2005, Liang (2008) found that the evolvement features of waste water exhaust gas and solid wastes does not accord with Environmental Kuznets Curve Hypothesis in Jiangsu Province, and the overall situation of the province still resides in the left of Environmental Kuznets Curve. The main reason why no turning point is shown on Environmental Kuznets Curve o f Jiangsu Province is that the effects of economic structure (positive) and technology (not distinct) could not counteract the scale effects (negative) (Liang 2008). Based on the economic and environmental data in Nanking from 1991 to 2003, the relationship between some environmental indicators and GDP per capita can be well characterized by Environmental Kuznets Curve (Wang, Cui & Chen 2006). Besides, Qiu (2006), Xu (2008), Ma (2007), Mu and Zhu (2008), Shen (2008), etc tested EKC in Xuzhou, Shandong, Jiangsu, Beijing and Shanghai. The above regional EKC researches indicate that relationship between environmental quality and economic development varies in different regions. However, most provincial researches are not reliable for two issues. One serious issue for all these provincial researches is that because of the lack of available data they are based on a short time period which may lead to spurious results. And another one is the lack of related tests, which will raise spurious regression results.

Many researches (Selden and Song 1994， Holtz-Eakin and Selden 1995) prove that the relationship between most pollutants and per capita income has the inverted U-shaped feature. However, other studies (Kaufman et al. 1998, Hettige et al. 2000) find that the relationship may not be inverted U-shaped, but U-shaped or N-shaped. "*A cubic (i.e. N-shaped) relationship between GDP and CO2 emissions is found to fit the data most appropriately for the period 1960-1999" in Austria* (Friedl and Getzner 2003, p.133). Such findings are also founded in Chinese empirical researches.

Studying the empirical case of Jiangsu Province, Ding and Nian (2010) made a simultaneous equation model and a main result is that the N-shaped relationship is existed between the pollution index and GDP per capital, which means that with the increase of income level, pollution level raises first, then decreases and increases at last. With the statistics data from 1998 to 2004, Li and Wang (2007) analyze the relationship between economic growth and three kinds of air pollutants in China by using panel data analysis for setting up panel model on thirty provinces. Different from most other EKC research results, no evidence proves the existence of inverted U curve, however an inverted N-curve well characterize the relationship between SO2 emission and economic growth (Li and Wang 2007).

Table.1. Results and weakness of provincial EKC researches

	Method	Model	Indicators	Period	Conclusion	Weakness
Wu,Dong&Song (2002)	Time series	Quadratic	12：SO_2, Solid, etc.	1985-1999	7-inverted U curve	Short period, no related tests
Li & Wang (2007)	Panel data (30samples)	Cubic, 3 control variables	3: SO_2, soot and dust	1998-2004	SO_2–inverted N curve;soot,dust-liner decreasing	Short period, no related tests
Zhang J. &Zhang Y.J (2006)	Time series	Cubic	3：waste gas,water, solid	1985-2003	Water,gas-N shape;solid inverted N shape	Short period, no related tests
Chen & Liu (2004)	Time series	Cubic	4：TSP,NO_X, CO, SO_2	1990-2001	TSP,NO_X,CO-inverted U curve, SO_2-U shape	No cointegration test
Liang (2008)	Time series	Quadratic	3:waste solid,gas, water	1986-2005	No inverse U curve	Short period
Wang, Cui & Chen(2006)	Time series	Quadrtic	5：COD, SO_2,waste water,gas, solid	1991-2003	Inverted U curve not for SO_2 and waste gas	Short period, no related tests
Qiu (2006)	Time series	Cubic	5 ： dust, SO_2,waste water,gas, solid	1988-2003	Inverted N shape-waste gas,water	Short period, no related tests
Xu(2008)	Time series	Quadratic	2: waste gas, water,solid	1994-2003	No inverted curve	Short period
Ma & Zhu (2007)	Comprison (17 industries)	---------	4:Waste water, SO_2,dust,soot	1991-2003	Not obvious	Need model
Mu(2008)	Time series	Cubic	6: waste water,gas, SO_2,etc.	1989-2006	N Curve	Short period, no related tests
Shen (2008)	Time series	Cubic	3:soot,waste water,gas	1985-2005	No inverted curve	Short period, no related tests

There has interaction between economic development and environmental quality, however most ECK researches are based on one equation model of econometrics. This means environment has no feedback effects on economic development. Based on this simplified model using OLS method, this kind EKC may be biased and unstable (Stern 1998). With the use of panel unit root tests and panel co-integration analysis, Guo and Li (2010) made use of data from 1991 to 2007 to look for the correlation between China's economic development and environmental pollution. The findings show that among five kinds of pollutant emission, only the relationship between industrial solid wastes and per capita GDP is well described by EKC, differently industrial waste gas and the economic development do not have co-integration correlation (Guo and Li 2010). Based on panel data of thirty provinces from 1996 to 2000, Peng and Bao (2006b) constructed simultaneous equation model (output and pollution) and results show that except for COD of waste water, other five pollutant indicators have inverted U-shape relationship with per capita GDP. Based on Stern Model, Yu et al. (2006) "*take SO2 emission as an environmental pollution index and apply regression analysis to 28 provinces/municipal cities' panel data except Guizhou, Tibet and Shanxi ones in China from 1999 to 2004. While the enlargement of economic scale, changes of industrial structure and energy structure deteriorate environment, enhancement of productivity, renovation and generalization of environmental protection technology reduce environmental pollution*" (Yu et al. 2006, p. 36).

The research of EKC has great effect on regional and global environmental policy. Environmental policies are based on empirical EKC findings, which are dependent on the choices of possible variables (in relative or absolute level). Friedl and Getzner (2003, p.135) state that "*four types of indicators are commonly employed for different pollutants or sorts of environmental degradation: (i) emissions per capita, (ii) emissions per gross domestic output (pollution intensity) or gross product, (iii) ambient levels of pollution (concentrations; impacts on a certain area), and (iv) total emissions*". "*Empirical studies have mostly used absolute measure of pollution like amount of emission or pollution rather than a relative measure (like pollution or emission per unit of output or per square kilometer, etc.). Use of a relative measure of pollution or emission, i.e., pollution intensity, may reveal a different form of relationship with income rather than an inverted-U shape (which may be true for absolute level). It should be noted in this context that the effect of income on pollution intensity tends to be negative in open economies, but positive in closed economies*" (Dinda 2004, p.448).

Although there have been much EKC researches in academia, Environmental Kuznets Curve has received much criticism. Many critical researches appeared in late 1990s mainly on theoretical issues (e.g., Stern et al., 1996; Stern, 1998; Arrow et al., 1995). Then more critical surveys are related to econometrics problems on EKC. Stern (2004, p.1429) summarized four categories of econometric critique on EKC: "*heteroskedasticity, simultaneity, omitted variables bias, and cointegration issues*". "*Stern et al. (1994) identified seven major problems with the early group of EKCs and their interpretation: a.) the assumption of unidirectional causality from growth to environmental quality and the reversibility of environmental change; b.) the assumption that changes in trade relationships associated with development have no effect on environmental quality; c.) econometric problems d.) data problems; e.) asymptotic behavior; f.) the mean-median income problem, g.) and the interpretation of particular EKCs in isolation from EKCs for other environmental problems*" (Stern 1998, p.180). Dinda (2004) described two kinds' critiques, conceptual and methodological. "*A conceptual critique: (1) EKC cannot fit for all* *typeset of pollutants. (2) EKC may not hold even in the long run. (3) Environmental quality may also deteriorate as population pressure increases more and more and economic growth may not automatically lead to a higher environmental quality. (4) The existence of EKC does not ensure to exist in future because of pressures of global competitions for environmental standards and regulations. (5) The concept of EKC cannot be applied to all the environmental factors such as land-use and bio-diversity, which are irreversible. A methodological critique: (1) Most studies use cross-section data and this means that in one panel economic development trajectory would be the same. But this assumption should be criticized because wide cross-country variables are observed in social, economical, political and biophysical factors that may affect environmental quality. (2) GED (global environmental degradation) has been ignored in existing literature. (3) A number of relevant factors have so far been omitted in EKC studies, such as transboundary and international externalities (Ansuategi et al., 1998; Copeland, 1996). (4) The non-availability of actual data on environmental quality is the major limitation of EKC studies. (5) The empirical robustness of EKC relation still remains an open issue*" (Dinda 2004, p.447-449).

3. Characteristic facts of Chinese economic growth and air pollutant emissions[1]

3.1 Chinese economic development

Since the reform and opening up, China has achieved an average annual GDP of close to 10% for more than 30 years with the guidance of effective policies. This kind of good performance helped Chinese solve food and shelter problem at first, and now Chinese are walking from basic well-off society to a comprehensive well-off society. Especially in the 21st century in the premise of an increasing economic output, China's economy maintained an average annual growth of 10% continuously. At the same time, as a result of eliminated deflation and non-obvious inflation, the quality of economic development increased and economic fluctuation decreased. However, China' economy as well as all countries' in the world has been affected when encountering the financial crisis in 2008. Although the crisis was so serious, it should be said that the timely four trillion economic stimulus plans, as well as the implementation of a series of measures played an important role in avoiding China, which has a higher ratio of dependence on foreign economies, from Japanese-style slump. After the crisis, it also speeds up the transformation of the economy and pays more attention to make economic development be more diversified and sustainable.

China's comprehensive national strength enhances obviously and Chinese living standards improve significantly because of sustained economic development. In 1978, China's GDP is only $216.5 billion. It surpassed Japan as the world's second largest economy in 2010, with nominal GDP of $6.04 trillion. From 1978 to 2010, China's foreign exchange reserves soared from $167 million to $2.8473 trillion, increasing 17050 times. Economic boom also improves China's infrastructure and people's living standards. In the industrial sectors, manufacturing ability and level grows rapidly and the innovative ability enhances.

With the development of economy, China's degree of opening-up has been growing fast and the economic relationship between China and other countries in the world becomes closer. China's GDP took up only less than 4% of world GDP when it just joined the WTO, rising to 9.3% in 2010. Especially in response to the global financial crisis, China took a package of measures to expand domestic demand and promote the world economic recovery efficiently. In 2010, the total trade volume was $2.9728 trillion, rising 34.7% than 2009. Among them, export volume was $1.5779 trillion, an increase of 31.3 than the previous year and import volume was $1.3948 trillion, a 38.7% increase from the last year. In addition, their customs revenue has been increasing rapidly, with 3.18 billion Yuan in 1980 and 1.2 trillion Yuan in 2010. The development of foreign trade makes a positive contribution to balance international payments and increase reserves. These changes led to the good and fast economic development and the increasing strength of the country for decades.

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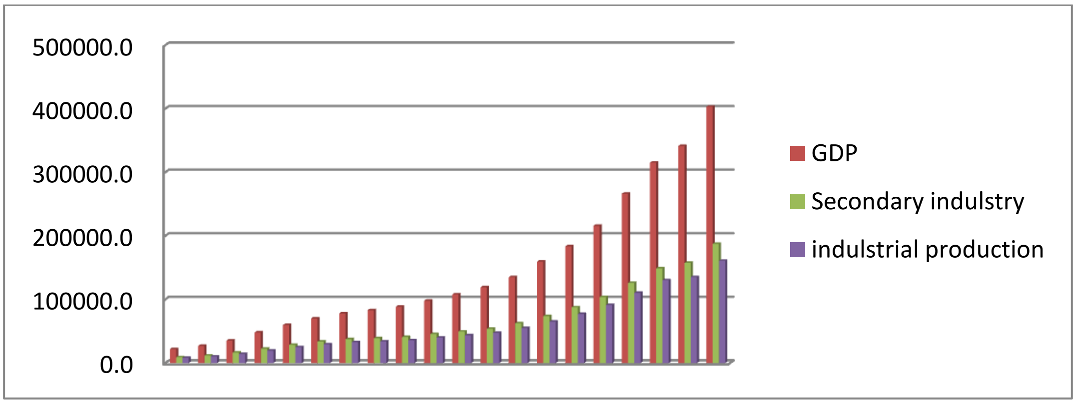
[1] a. Parts of this section were used in the final paper for EKHM 40 Research Design (Research Proposal EKHM 40) ---- Xinyu Yu

b. All the data in this section are gathered from China statistical Yearbook, China Environment Bulletin, and China Environment statistical Yearbook.

c. All the GDP data in this section are in nominal terms.

Figure.2.Tendency chart of Chinese economic growth 1991-2010 (billion Yuan)



Source: China Statistical Yearbook

Table.2. Change trend of proportions of three industries in GDP and per capital GDP

Year	Agriculture	Industry	Service	per capital GDP
1991	24.5%	41.8%	33.7%	1893
1992	21.8%	43.5%	34.8%	2311
1993	19.7%	46.6%	33.7%	2998
1994	19.9%	46.6%	33.6%	4044
1995	20.0%	47.2%	32.9%	5046
1996	19.7%	47.5%	32.8%	5846
1997	18.3%	47.5%	34.2%	6420
1998	17.6%	46.2%	36.2%	6796
1999	16.5%	45.8%	37.8%	7159
2000	15.1%	45.9%	39.0%	7858
2001	14.4%	45.2%	40.5%	8622
2002	13.7%	44.8%	41.5%	9398
2003	12.8%	46.0%	41.2%	10542
2004	13.4%	46.2%	40.4%	12336
2005	12.1%	47.4%	40.5%	14185
2006	11.1%	47.9%	40.9%	16500
2007	10.8%	47.3%	41.9%	20169
2008	10.7%	47.4%	41.8%	23708
2009	10.3%	46.2%	43.4%	25608
2010	10.1%	46.8%	43.1%	29992

Data source: calculation based on data from China statistical Yearbook

(See Table.2) During twenty years from 1991 to 2010, China's gross domestic product was growing rapidly and continually. GDP was 2.18262 trillion Yuan in 1991, and by 2010 it had increased to 40.326 trillion Yuan. Compared in comparable prices, it increased 1747%. And per capital GDP increased from 1893 Yuan in 1991 to 29992 Yuan in 2010. In the same period, China's industrial structure improved continuously. Service industry developed fast and its proportion increased. From 2006 to 2010, the Service sector grew at an average annual rate of 11.9%. The share of service in total GDP was 43% in 2010, 9.4 percent points higher than 1991. For industry, its proportion in GDP dropped from 47.4% in 2005 to 46.8% in 2010. And the proportion of agriculture declined from 12.1% in 1991 to 10.2% in 2010.

3.2 Air pollutant emissions

As the economy has boomed, environmental quality has improved in general trend, but environmental pollution in many cities and regions is still severe. There appears the fact that the economic development and environmental development disconnected because the government didn't pay enough attention on environmental management and optimization.

Overall, urban air quality tends to be friendly, but air pollution is still serious. Airborne pollution mainly derives from coal combustion emission and particulates are the main parts of air pollution. In 2010, 471 counties and cities monitored environment and air quality including sulfur dioxide, nitrogen dioxide, carbon dioxide and particulates. Among them only 3.6% of those attained Grade 1[2]. As shown in table below, acid rain occurred in 50.4% of all the 494 cities which were monitored. 160 cities accounting 32.4% of total has the acid rain frequency of more than 25%. 54 cities (11%) have the acid rain of more than 75%.

Table.3.Frequency statistics of acid rain in 2010

Acid rain frequency	0	0 ~ 25%	25% ~ 50%	50% ~ 75%	≥75%
City number	245	89	57	49	54
proportion (%)	49.6	18.0	11.5	9.9	11.0

Source: China Environment Bulletin 2010

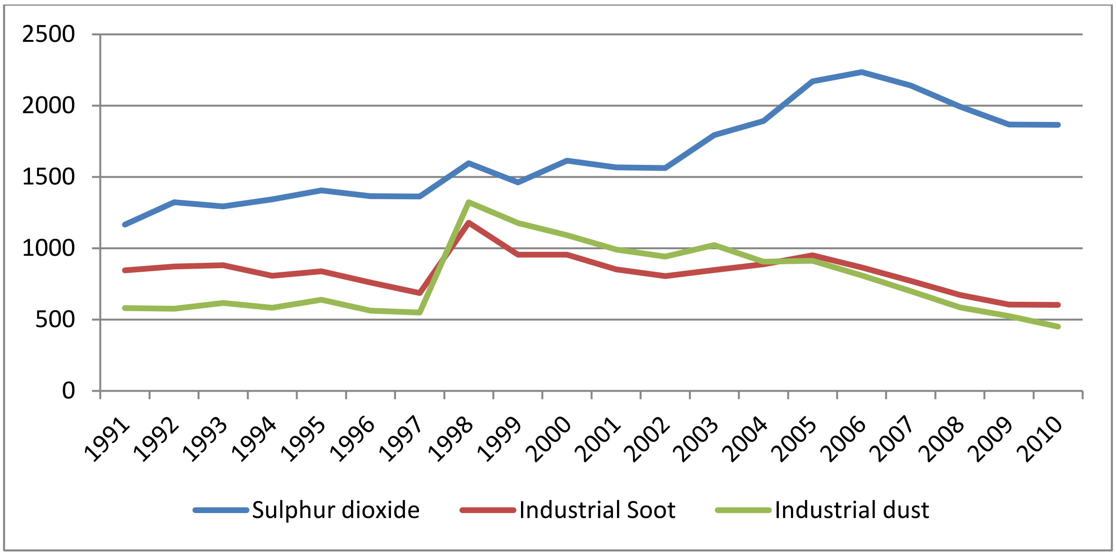
For more than twenty years, China has not controlled air pollution widely. However, the performance improved recently aiming at controlling conventional pollutants such as sulfur dioxide, soot and dust.

Industrial atmospheric pollutants changed obviously. The emission of industrial sulfur dioxide reduced from 21.684 million tons in 2005 to 18.644 million tons, a decrease of 16.3%. And in 1998 the emission of industrial soot was 11.785 million tons, by 2010 reduced to 6.032 million tons, a drop of 48.9%. For industrial dust, its emission

[2] Grade 1 is the highest standard for air quality in China. This standard is the general assessment of concentrations of pollutants including SO^2, TSP, PM10, NO_X, NO_2, CO, O_3, P_b, B[a]P, and F (fluoride).

decreased from 13.211 million in 1998 tons to 4.487 million tons in 2010, a decrease of 66%.

Figure.3.1991-2010 emission trends of industrial sulfur dioxide, industrial soot and industrial dust (10000tons)



Data source: China Environment statistical Yearbook

Although these pollutants have decreased, the serious situation of environmental pollution didn't get torsion. For example, atmospheric nitrogen oxides pollution has presented obvious deterioration (translation, China Environment Bulletin). As a result, some cities have already appeared the phenomenon of photographic smog.

4. Hypothesis, Data, and Model

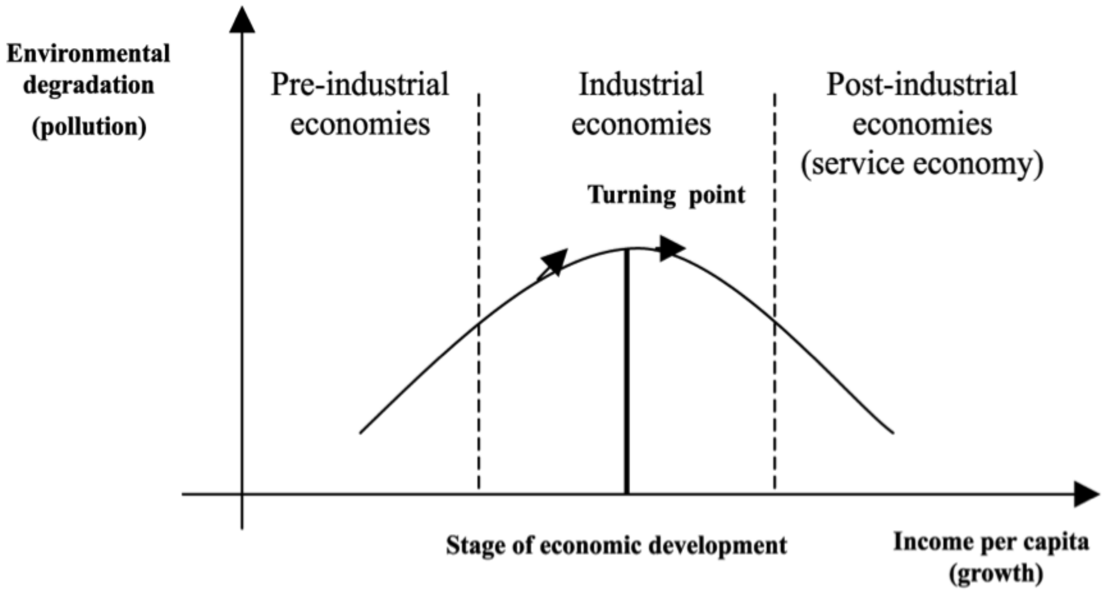
4.1 EKC hypothesis

In 1970s, "limits of growth" by Rome Club suggests that the continued economic growth economy is base on nature (energy and material). The growing process will produce more and more waste and cost more and more natural resources to degrade the quality of environment. As a result, economic growth should be slowed down to seek a steady state (Meadows et al 1972).

On the contrary, the environmental Kuznets curve (EKC) suggests another point of view. It assumes that the relationship between environmental quality and economic development can be described by inverted U curve. In detail, in the first step of economic growth, environmental indicators will become worse and then reach to the highest level. After the turning point, with the growth of economy, environment pressure will be alleviated.

"*At low levels of development both the quantity and intensity of environmental degradation is limited to the impacts of subsistence economic activity on the resource base and to limited quantities of biodegradable wastes*" (Panayotou, 1993, p.1). According to his statement, with the fast development of agriculture and the early industrial take-off, the speed of resource regeneration is slower than that of the use of resources and waste increases its quantity, intensity and toxicity. However, with the sustained economic growth, industries change the traditional model which has the features of high-consumption, high-pollution and high-emission and more companies start to turn into informative and service ones. In addition, with the help of complete environmental regulations, increasing environmental attention and awareness, environmental degradation is on the decline at last (Panayotou, 1993, p.1).

Figure.4. the EKC relationship between environmental degradation (pollution) and income per capita (economic growth)



Source: Panayotou (1993)

In this research, empirical panel analysis is to check whether the relationship between environment indicators (SO_2, industrial soot, and industrial dust) and economic indicator can be described by Environmental Kuznets Curve. As a result, empirical hypothesis of this research: with the increase of real GDP per capita, the emission of industrial sulphur dioxide, industrial dust and industrial soot increases at the first development stage and then deceases as GDP per capita grows constantly.

4.2 Data

In the studies, scholars usually use two kind variables to indicate environmental degradation. One is the emission of pollutant, and another is environmental concentration of pollutant. "*Emissions represent the amount of pollution generated by economic activity without regard to the size of the area into which the pollutants are emitted. Concentrations measure the quantity of pollutants per unit area or volume without regard to the activity that emitted them. Neither emissions nor concentrations measure accurately all aspects of the relation between economic activity and environmental degradation*" (Kaufmann etc. 1998, p.210). As a result, the disadvantages should be known and research results should be explained in the right way.

Emissions cannot reflect the real level of environmental degradation and they only measure the potential damage of economic activities on environment, because their impacts can be reduced aggravated by the factor of size of the area (Kaufmann etc. 1998). For example, if two countries have the same emission of one atmospheric pollutant, of course the emission will have a smaller impact on the country with larger territory area. However, the concentration of one pollutant will solve this problem. At the same time, there are shortcomings to use concentrations of pullutants. First, concentration may not have correlation with the severities of environment degradation because direct relation may not exist between concentration and exposure (Smith 1993, cited by Kaufmann etc. 1998). Second, if the pollutant is "*long lived or appear as the result of decay process*" (p.211), concentration may not inflect the environmental degradation of current economic activities (Kaufmann etc. 1998). Third, Kaufmann etc. (1998) suggest that concentration can be effected greatly by space and time.

Compared with data of emissions, the concentration data are more reliable. While concentration of one pollutant is created by physical measurements which usually are accurate, "*emission data are generated from conversion rates applied to economic data, both of which can be unreliable"* especially in developing countries (Kaufmann etc. 1998, p.211).

One limitation of data is that the analysis is based on the data of emissions of three atmospheric pollutants. As one of the developing countries, the statistics of pollutants may not be accurate due to the use of methods, official reasons, etc. Besides, the statistical scope was changed in 1998. Emissions in small towns were not included in the statistics before 1998. Although the number of firms in towns is small before 1998, the change of statistics scope has some effects on the empirical results.

Based on the data of 29 provinces in China in the period from 1991 to 2010, panel data analysis will be applied to do EKC research by using real gross domestic product as the economic indicator, and the emissions of industrial sulphur dioxide, industrial dust, and industrial soot as environmental indicators. The selected 29 mainland provinces are Beijing, Tianjin, Hebei, Shanxi, Neimenggu, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Sichuan, Guizhou, Yunnan, Shanxi, Gansu, Qinhai, Ninxia and Xinjiang. All the economic data and provincial population data are collected in the China Statistical Yearbook. Environmental data are collected from China Environmental Yearbook and provincial Environmental Statistical Yearbook. Besides, price index data is available in World Bank Database.

E -- pollutant emission, e.g. industrial sulphur dioxide emission (in ten thousand tons), industrial dust emission (in ten thousand tons), and industrial soot emission (in ten thousand tons).

GDP -- gross domestic product (in RMB yuan).

P -- population.

Environmental quality can be measured in many ways, and the different measurements of environmental quality will have different impacts on the relation between economic growth and environmental pollution. In my research, the absolute emissions of three atmospheric pollutants are chosen as environmental indicators. Since there were no data of industrial sulphur dioxide, industrial dust and industrial soot for most provinces before 1991, the time span is from 1991 to 2010. 580 observations are comprised of 29 provinces' data. Tibet together with Chongqing is excluded. For Tibet, it is difficult to obtain original data for environmental indicators. In addition, it should be illustrated that Chongqing's data front 1991-1996 are not available for the reason that it was set to be a municipality directly under the central government in 1997. And the environmental data of Sichuan before and after 1997 have a big difference. In order to ensure the continuity of data of Sichuan, the combination of Sichuan's and Chongqing's data after 1997 is used as Sichuan's data.

In view of the provincial GDP data that are at current prices in China Statistical Yearbook, they should be converted into fixed prices. The national price index is from World Bank Database (CPI-Consumer Price Index, benchmark year = 1990). The next step is to calculate the economic indicator in per capita.

4.3 The Model

◎Variables

Based on the economic and environmental data of twenty-nine provinces from 1991 to 2010, panel data approach is used to analyze the relationship between economic growth and emissions of atmospheric pollution (SO_2, industrial soot, industrial dust). While economic growth is measured by per capita GDP, the environmental degradation is reflected by emissions of three atmospheric pollutants (Industrial sulfur dioxide, Industrial dust and Industrial soot). Both independent variable (GDP per capita) and dependent variables (emissions of three pollutants) are in natural logarithm so that data will be smoother to get higher precision of analysis.

◎Establishing model

There are many factors affecting the relationship between environmental pollution and economic growth, among them are "*the size of the economy, the industrial structure, population density, the vintage of the technology, the demand for environmental quality, the level of environmental protection expenditures, international trade and so on*" (Song, Zheng and Tong 2008, p.385). As a result, a comprehensive analysis of EKC is complicated. Besides, affecting by different factors, the relationship by environmental degradation and economic growth may be different and complicated. For simplifying the analysis and proving the existence of pure EKC, those factors related to the emission of pollutants are not involved in the model.

Two forms of simplified model are often used to examine the existence of EKC relationship between environmental pollution and economic growth. One is the quadratic polynomial; the second is cubic polynomial including constant term or time terms. Based on the cubic polynomial of the simplified model, variable will be the per capita GDP. This simplifying model does not consider the impacts of trade, technology progress and policy, economic structure, regional difference, etc. This model is homogeneous because the three parameters, which are not dependent on regions, are assumed to have homogeneity. The simplified EKC model is given by:

$$\ln\left(E_{it}\right) = \alpha_i + \beta_1 \ln X_{it} + \beta_2 [\ln X_{it}]^2 + \beta_3 [\ln X_{it}]^3 + \varepsilon_{it} \qquad (1)$$

$$X = \frac{GDP}{P}$$

i-Province (i=1, 2…N), t-year (t=1, 2…T), α_i -cross-section effect, ε_{it} -random disturbance, E_i- pollutant index, X_{it}-per capita GDP, $\beta_1, \beta_2, \beta_3$-coefficience

In this model, it is not assumed that all the provinces have the same shape of EKC for the reason that both fixed effects and random effects may be accepted. The further tests will be showed in next section. With different results of parameters in Eq. (1), there exist various shapes of pollution-income relationship. Follows are possible forms of relationships between environmental degradation and economic growth.

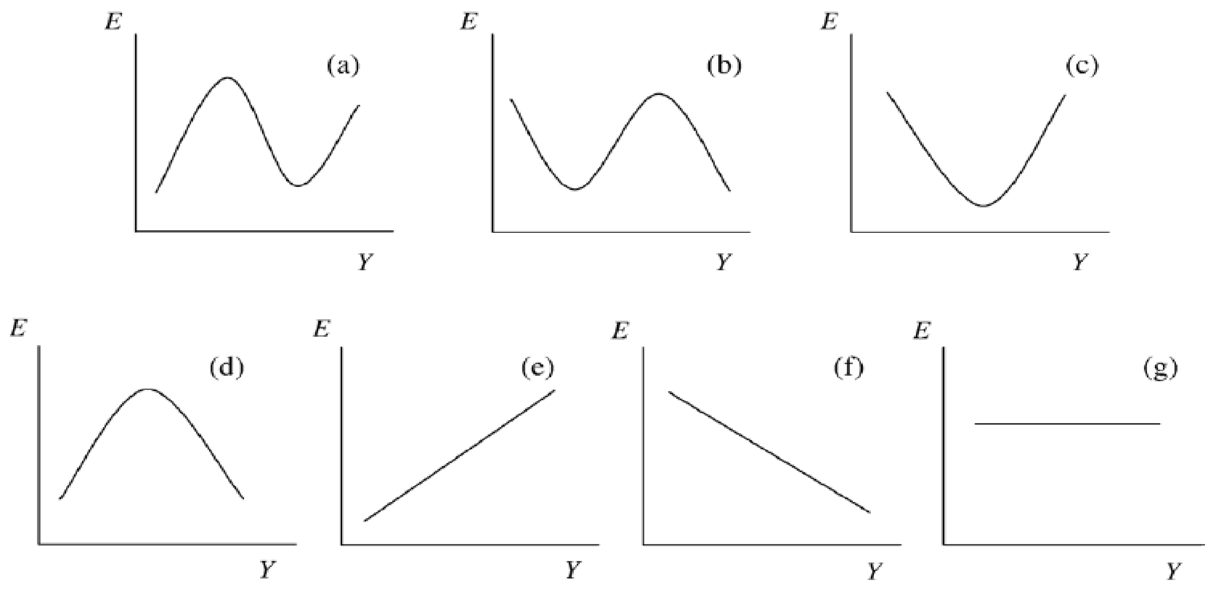


Figure.5. various relationships between environmental degradation and economic growth

Source: Song, Zheng and Tong (2008)

1. If β_1>0 , β_2<0 and β_3>0 , indicating "N" shape (Figure.5a.); otherwise, β_1<0 , β_2>0 and β_3<0, it is inverted "N" shape (Figure.5b.).
2. If β_1>0, β_2<0 and β_3=0, it represents an inverted "U" shape, which reflects EKC relationship (Figure.5d.)； If β_1 <0, β_2 >0 and β_3 =0, it reveals "U" shape (Figure.5c).
3. If β_1 >0, and β_2=0, β_3=0, it represents increasing linear relationship (Figure.5e.).
4. If $\beta_1 < 0$, and β_2 =0, β_3 =0, it reveals a monotonically decreasing linear relationship (Figure.5f.).
5. If $\beta_1 = \beta_2 = \beta_3 = 0$, it indicates a level relationship (Figure.5g).

TP (turning point of inverse U-shape EKC): GDP=Exp ($-\beta_1/2\beta_2$)

4.4 Model Specification

Panel data is widely used in modeling on studying economic issues because it has both time-series and cross-section characters. Model specification has great effects on the accuracy of parametric estimations. First is to do modeling specifications to determine the certain form of model through F test, Hausmann test, panel model test, wald test. F test is used for testing if there are specific individual effects. Based on Hausman test results, one model will be chose from fixed effect model (FE) and random effect model (RE). Then taking consideration of results of estimation of model and wald test, cubic model or quadratic model will be selected for every pollutant.

◎F test

The first step is to test whether specific individual effects in Eq. (1) for every province are existed. F test can be used to test fixed effects and the detailed explanation can be found in econometrics books, e.g. Baltagi (2002).

$$H_0: \alpha_1 = \cdots = \alpha_{N-1} = \alpha$$
$$F_0 = \frac{(RRSS - URSS)/(N-1)}{URSS/(NT-N-K)} \sim F_{N-1.N(T-1)-K}$$

"*This is a simple Chow test with the restricted residual sums of squares (RRSS) being that of OLS on the pooled model and the unrestricted residual sums of squares (URSS) being that of the LSDV regression*" (Baltagi 2005, p.11). The hypothesis means that different provinces have the same individual effects. And if the hypothesis is rejected, it means different provinces have different intercept terms and I should do further test for choosing random effects or fixed effects. As shown in the table, all the F statistics are significant at level of 5% which reveals that specific individual effects are valid in Eq.(1).

Table.4. F test for fixed effects

Null hypothesis of F test	Industrial SO2		Industrial dust		Industrial soot	
	Quadratic	Cubic	Quadratic	Cubic	Quadratic	Cubic
$H_0: \alpha_1 = \cdots = \alpha_{N-1} = \alpha$	311.3837*	341.1402*	137.9193*	137.5193*	177.7759*	181.2922*

Figures in the table are the resulting F-statistics. * denotes the rejection of the null hypothesis at 5% level of significance.

◎Hausman test

The second step is to take Hausman test to test whether randon effect model or fixed effect model should be selected.

H_0: individual effect is not related to regression variable (X_{it})—random effect model

H_1: individual effect is related to regression variable (X_{it}) –fixed effect model

$$H = (\beta_{RE} - \beta_{FE})'[\mathrm{Var}(\beta_{FE} - \beta_{RE})]^{-1}(\beta_{RE} - \beta_{FE}) \sim X^2(K)$$

Where β_{RE}, β_{FE} indicates the estimated coefficient of random effect model and fixed effect model respectively, $\mathrm{Var}(\beta_{FE} - \beta_{RE})$ is the covariance matrix of coefficient vector$(\beta_{RE} - \beta_{FE})$.

Based on the assumption of random effect model, H_0 is asymptotically distributed as $X^2(K)$ and K represents the dimension of slope vectorβ. If H statistics is more than critical value, then the null hypothesis is rejected.

Table.5. Hausman test results

Null hypothesis of Hausman test	Industrial SO2		Industrial dust		Industrial soot	
	Quadratic	Cubic	Quadratic	Cubic	Quadratic	Cubic
Chi-Sq. Statistic	1.731	4.607	2.000	6.465	2.000	3.000
Prob.	0.421	0.203	0.269	0.091	0.607	0.449
Result	RE	RE	RE	FE	RE	RE

As shown in Table.5, all the results suggest that the null hypothesis should be accepted with the exception of the cubic form of industrial dust. It means that the fixed effect model is suitable for cubic polynomial of industrial dust in the level of 10% and the rest should choose random effect model.

◎Estimation of the model and Wald test

Thirdly, the logarithm model needs further pre-specified to choose quadratic or cubic forms because there may have seven possible forms of pollution-income relationship as previous shown in Figure.5. T statistics for regression coefficients and adjusted R^2 are checked. If one form of model cannot be selected based on the results of t statistics and adjusted R^2, Wald test will be applied.

Table.6

Estimation of the model and the resulting Wald test

Variables	Industrial SO2		Industrial dust		Industrial soot	
	Quadratic	Cubic	Quadratic	Cubic	Quadratic	Cubic
ln(GDP/P)	2.8620*(10.1123)	-26.0926*(-7.7786)	6.6140*(16.3352)	-13.0404*(-2.5849)	2.5101*(7.3780)	-16.4533*(-3.8989)
$[\ln(GDP/P)]^2$	-0.1491*(-8.9495)	3.2420*(8.2720)	-0.3976*(-16.6759)	1.9042*(3.2306)	-0.1576*(-7.8682)	2.0633*(4.1846)
$[\ln(GDP/P)]^3$		-0.1316*(-8.6595)		-0.0893*(-3.9083)		-0.0862*(-4.5079)
Ajusted R2	0.4274	0.9459	0.8925	0.8953	0.9040	0.9073
Turning point		1138 12200		314 4859		2274 3675
Wald test	H_0 : the quadratic curve H_1 : the cubic curve					
Wald statistic	t-statistic	F-statistic	Chi-square			
Industrial dust	-3.9791*	15.8333*	15.8333*			
Industrial soot	-4.5418*	20.6286*	20.6286*			

Figures in parentheses are t statistics for regression coefficients. "*" denotes that the parameter estimate is significant at 1%. "--" denotes no existence of the turning point.

As shown in Table.6, for all the three pollutants (industrial SO_2, industrial dust and industrial soot) all the parameters with both quadratic and cubic log-log model are significant at 1% of significance. According to the results of t statistics for regression coefficients, a more appropriate model cannot be selected from these two models. In accordance with the results of adjusted R^2, the closer the value is to 1, the better the goodness of fit is. As a result, the quadratic form is excluded for industrial sulphur dioxide. But for other two pollutants, it is hard to decide which form is preferential.

At last, the Wald test is ran to select the better one from the quadratic form and the cubic form. The result of Wald test reveals that the null hypothesis can be rejected at the significance level of 1% when using all the three pollutants as the indicators of environmental degradation. The Wald test result of industrial sulphur dioxide shows the same choice as the result of parameter estimates.

In a word, the pre-specification result shows that a cubic logarithm model is appropriate to test the relationship between the emissions of three pollutants and per capita GDP. For industrial sulphur dioxide and soot, random effect model is used for panel data analysis, but fixed effect model is preferred for industrial dust. In the next section, further econometric tests will be done to test whether the data is stationary or no-stationary and whether there is co-integration between emissions of pollutant and per capita GDP.

5. Econometric methods and empirical results[3]

In Section 5, two econometric methods, panel unit root tests and panel cointegration test will be carried out. The aim of unit root tests is to test whether there is unit root for variables or whether the data is stationary. Four methods will be used including LL (Levin, Lin and Chu 2002), IPS (Im, Pesaran, and Shin 1997), Fisher ADF (Maddala and Wu 1999) and Breitung (2000). Each method has its specialty and shortage. For increasing the credibility of the result, these four tests are applied in this research. If the result shows that the two panel data sets (e.g. Ln(GDP), ln(Soot)) are stationary in different orders, it reveals that there is no integration between the emission of pollutant and GDP per capita. Therefore, the regression estimation of pollution-income relationship will be spurious. But if two variables are stationary in the same order, then cointegration between an environmental indicator and an economic indicator should be tested. In the following step, Pedroni's (2000) panel conintegration test is used to check the cointegration relationship between the two indicators.

After these two tests, the empirical findings will be presented and analyzed.

5.1 Unit Root Test

◎LLC - Levin, Lin and Chu

Levin, Lin and Chu (2002, cited by Baltagi 2005) suggested that individual unit toot tests are little powerful against alternative hypotheses when the deviations from equilibrium are greatly persistent. Then they make a test that have more power than individual unit root tests for each cross-section. LLC is restrictive that ρ should be homogeneous.

$$\Delta y_{it} = \rho y_{i,t-1} + \sum_{L=1}^{p_i} \theta_{iL} \Delta y_{i,t-L} + \alpha_{mi} d_{mt} + \epsilon_{it} \quad i = 1,2,\dots,N; t = 1,2,\dots,T; m = 1,2,3$$

Where i is the number of each province; t indicates time variable; α_{mi} is the corresponding vector of coefficients for model m=1,2,3,; d_{mt} indicates the vector of deterministic variables (intercept or trend), $d_{1t} = \{0\}, d_{2t} = \{1\} \text{ and } d_{3t} = \{1, t\}$; $\epsilon_{it} \sim \text{i.i.d.}\left(0, \sigma_i^2\right)$, means random error has no serial correlation for all the i and t.

H_0: $\rho_i = \rho = 0, \text{for all i}$, the null hypothesis is that each individual time series is stationary.

H_1: $\rho_i = \rho < 0, for\ all\ i$, the alternative hypothesis is that each time series does not have a unit root.

Three steps are needed to do LLC test. Step 1 is to perform ADF (augmented Dickey-Fuller) regression for each cross-section. Step 2 is to estimate the ratio of long-run to short-run standard deviations. Step 3 is to compute the panel test statistics.

The conventional test statistics: $t_p = \frac{\hat{\rho}}{\hat{\sigma}(\hat{\rho})}$

[3] Parts of this section are based on the course slides which made by Georges Bresson (Georges Bresson, ERMES, Paris University, June 2002) and on the content of Chapter 12 of Textbook (Econometric Analysis of Panel Data) by Baltagi (2005).

The adjusted test statistics: $t_\rho^* = \frac{t_p - N\tilde{T}\hat{S}_N \hat{\sigma}_{\tilde{\varepsilon}}^{\,2} \hat{\sigma}(\hat{\rho}) \mu_{m\hat{T}}^*}{\sigma_{m\hat{T}}^*}$, t_ρ^* is asymptotically distributed as N(0,1).

For the reason that exogenous regressors may decrease the power of the test, it is necessary to check whether constant terms and trend should be adopted before test. Besides, LLC has its limitations. "*The test crucially depends upon the independence assumption across cross-sections and is not applicable if cross-sectional correlation is present. Second, the assumption that all cross-sections have or do not have a unit root is restrictive*" (Baltagi 2005).

◎IPS – Im, Pesaran and Shin

Based on the augmented Dickey-Fuller (ADF), IPS test uses separate unit root tests for all the cross-sections and average the ADF tests. Follows is the formula of $\bar{t}$:

$$\bar{t} = \frac{1}{N}\sum_{i=1}^{N} t_{\rho_i}$$

The null hypothesis, that each series has a unit root, is the same as LLC. But the alternative one for IPS is that not all the individual series have unit roots.

H_0: $\rho_i = \rho = 0, \text{for all i}$; H_1: $\rho_i < 0, for\ i = 1,2,3, \dots N_{1,}\ \rho_i = 0 \text{ for } i = N_1, \dots N$;

The average of ADF statistics can be used to compute t_{IPS}:

$$t_{IPS} = \frac{\sqrt{N}\left(\bar{t} - E(\bar{t})\right)}{\sqrt{var(\bar{t})}} \approx N(0\ ,\ 1)$$

Where $\bar{t}$ is the average of individual ADF statistics; $E(\bar{t})$ indicates the mean of t_{ρ_i}; $\sqrt{var(\bar{t})}$ is the variance of individual specific test statistics (t_{ρ_i}). And IPS is asymptotically distributed as N (0, 1). Based on Monte Carlo experiments, IPS test statistics is better than LLC test with a small sample.

◎Breitung's test

Breitung (2000) researches the power of LLC and IPS and makes comparison with other alternative tests. Then Breitung finds that LLC and IPS tests' power will be decrease a lot with individual specific trends. "*This is due to the bias correction that also removes the mean under the sequence of local alternatives*" (Baltagi 2005). Breitung suggests a test statistic without adopting a bias adjustment. Based on results of Monte Carlo experiments, the test has higher power than LLC or the IPS. The experimental results show that the power of LLC and IPS tests is very sensitive to the specification of the deterministic terms (Baltagi 2005).

The detail of Breitung's test can be found in Breitung's research paper (2000) and in the econometrics textbook written by Baltagi (2005).

◎Fisher ADF:

Fisher ADF test was suggested by Maddala and Wu (1999). P_λ in Fisher ADF is not affected by the number of lags. For this issue, it can cover Tehran shortage of LLC and IPS. Based on the model:

$$\Delta y_{it} = \rho y_{i,t-1} + \sum_{L=1}^{p_i} \theta_{iL} \Delta y_{i,t-L} + \alpha_{mi} d_{mt} + \epsilon_{it} \quad i = 1,2, \dots, N; t = 1,2, \dots, T; m = 1,2,3$$

P statistics :

$$P_{\lambda} = -2\sum_{i=1}^{N} \ln p_i \sim \chi^2(2N)$$

The null hypothesis and alternative hypothesis of Fisher ADF are the same with IPS's.

H_0: $\rho_i = \rho = 0, \text{for all i}$; H_1: $\rho_i < 0, for\ i = 1,2,3, \ldots N_{1,}\ \rho_i = 0 \text{ for } i = N_1, \ldots N$;

◎Results of unit root tests

For unit root test of LLC, IPS and Fisher ADF, it is important to choose to employ no exogenous regressors, or to include individual intercept terms, or to use content and trend. Based on the graphs of series, individual constant and trend should be included for all the variables (ln(G/P), $[\ln(G/P)]^2$, $[\ln(G/P)]^3$, $\ln(SO_2)$, ln(Dust), ln(Soot)). However, time trend should be excluded for seriesof Δln(GDP/P), $\Delta[\ln(GDP/P)]^{2,}$, $\Delta[\ln(G/P)]^3$, $\Delta\ln(SO_2/P)$, Δln(Dust/P), and Δln(Soot/P). The figures in italics in the below table are the specific results of panel root tests.

Table.7.Panel unit root tests

Methods	Specification	ln(G/P)	$[\ln(G/P)]^2$	$[\ln(G/P)]^3$	$\ln(SO_2)$	ln(Dust)	ln(Soot)
LLC	individual intercept	8.81356	10.6968	12.9959	-2.99543*	-0.80463	-1.4239
	individual intercept and trend	*2.2144*	*3.53027*	*4.36522*	*-1.17464*	*-2.01634*	*-3.07363**
	none	22.6206	26.269	27.6526	3.27285	-2.35476*	-4.02977*
IPS	individual intercept	13.4702	15.6467	17.7779	-1.91785*	-0.63009	-2.2802*
	individual intercept and trend	*4.33473*	*6.68081*	*8.53717*	*-2.87321*	*0.2565*	*-2.42948**
ADF	individual intercept	1.92754	1.6745	0.99635	90.3552*	62.1759	96.1613*
	individual intercept and trend	*35.972*	*24.0342*	*18.4561*	*86.8160*	*53.0815*	*93.5740**
	none	0.61673	0.54055	0.50447	17.9976	49.1653	79.8582*
Breitung	individual intercept and trend	*0.7969*	*3.43575*	*5.71019*	*-1.4656*	*-0.36524*	*-1.21086*
		Δln(G/P)	$\Delta[\ln(G/P)]^2$	$\Delta[\ln(G/P)]^3$	Δln(S/P)	Δln(D/P)	Δln(SO/P)
LLC	individual intercept	*-8.8964**	*-8.09997**	*-6.91746**	*-18.1860**	*-18.5319**	*-18.6168**
	individual intercept and trend	-11.2501*	-11.4182*	-11.7245*	-15.3985*	-16.4211*	-15.2481*
	none	-4.63974*	-3.52989*	-2.42085*	-20.7714*	-22.2936*	-22.4292*
IPS	individual intercept	*-6.29136**	*-5.54736**	*-4.54872**	*-16.5177**	*-15.9594**	*-17.8375**
	individual intercept and trend	-6.48230*	-7.33667	-7.92937*	-13.3360*	-13.2068*	-13.7688*
ADF	individual intercept	*131.35**	*120.93**	*106.596**	*335.274**	*323.127**	*359.484**
	individual intercept and trend	135.965*	149.932*	159.913*	249.876*	257.815*	262.059*
	none	81.6030*	67.4175**	56.7419	420.576*	488.223*	498.187*
Breitung	individual intercept and trend	-2.47620*	-1.3811***	-0.36629*	-11.1770*	-10.1945*	-7.65380*

"*" denotes the rejection of the null of nonstationary at the 5% level of significance respectively.

As shown in Table.7, for all the variables in level, the null hypothesis of unit root can only be rejected for soot at 5% level of significance. The results show that all the series are nonstationary in level with the exception of soot. And for the first differences of all the variables, the result illustrates that all the series are stationary. As a result, all the panels are integrated of order one-I (1) except soot.

5.2 Co-integration Tests

The co-integration test in this section is aimed at testing if there is long-run relationship between per capita GDP and emission of pollutant. Based on principles of ADF and PP, Pedroni Test uses two-step strategy (Song, Zheng and Tong 2008). Making use of residuals from the model:

$$Y_{it} = \alpha_i + \delta_i t + \theta_t + \beta_{1i} x_{1it} + \cdots + \beta_{Mi} x_{Mit} + \varepsilon_{it} \qquad i = 1, \dots, N; t = 1, \dots, T$$

Where N is the number of cross-sections, T indicates time observations, and M is the number of regressors, α_i indicates individual effect, δ_i represents individual specific linear trend, θ_t is the time effect. And β_{Mi} can be heterogeneous in this model.

There are two categories of seven tests in Pedroni tests which are aimed at testing the staionarity of the error processes of the estimated equation. Four statistics of one category, containing v-statistic, ρ-statistic, PP-statistic, and ADF-statistic, are described by "Panel". These four statistics are based on within-dimension method and have a restriction that autoregressive parameter are the same across all cross sections on the estimated residuals. However, other three statistics allow autoregressive parameter to be different across the cross-sections. These three statistics, which are based on between-dimension method and contain ρ-statistic, PP-statistic and ADF-statistic, are described by "Group".

All the seven Pedroni statistics and statistic expressions are in Table.8.

Statistics	Expressions of statistics
Panel V	$Z_v^\omega = \left(\sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2\right)^{-1}$
Panel Rho	$Z_\rho^\omega = \left(\sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2\right)^{-1} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2}(\hat{e}_{i,t-1}\Delta\hat{e}_{it} - \hat{\lambda}_i)$
Panel PP	$Z_{pp}^\omega = \left(\tilde{\sigma}_{NT}^2 \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2\right)^{-1/2} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2}(\hat{e}_{i,t-1}\Delta\hat{e}_{it} - \hat{\lambda}_i)$
Panel ADF	$Z_t^\omega = \left(\tilde{s}_{NT}^{*2} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{*2}\right)^{-1/2} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{*}\Delta\hat{e}_{it}^{*}$
Group Rho	$Z_\rho^B = \sum_{i=1}^N \left(\sum_{t=1}^T \hat{e}_{i,t-1}^2\right)^{-1} \sum_{t=1}^T (\hat{e}_{i,t-1}\Delta\hat{e}_{it} - \hat{\lambda}_i)$
Group PP	$Z_{pp}^B = \sum_{i=1}^N \left(\sum_{t=1}^T \hat{s}_i^{*2} \hat{e}_{i,t-1}^{*2}\right)^{-1/2} \sum_{t=1}^T \hat{e}_{i,t-1}^{*}\Delta\hat{e}_{it}^{*}$
Group ADF	$Z_t^B = \sum_{i=1}^N \left(\hat{\sigma}_i^2 \sum_{t=1}^T \hat{e}_{i,t-1}^2\right)^{-1/2} \sum_{t=1}^T (\hat{e}_{i,t-1}\Delta\hat{e}_{it} - \hat{\lambda}_i)$

Source: Pedroni (1999)

Based on Monte Carlo experimental results, Pedroni (1999) state that the Group Rho is the most conservative test of the seven stastistics in terms of N and T, besides Group Rho, Panel Rho and Panel V have quite low power when N and T are low (cited by Kerenz 2012). According to the results in Table.9, only the results of Group Rho are worst that the null hypothesis cannot be rejected. The rest results show that the null hypotheses of no cointegration are strongly rejected for the two pollutants (see Table.9). As a consequence, the panel cointegration tests support that there is long-run relationship between GDP per capita and the emission of two pollutants.

Table.9 Result of Panel cointegration test

Statistics	Industrial SO_2	Industrial dust
Panel v-Statistic	3.1767*	1.7134**
Panel rho-Statistic	-5.2801*	-2.1541*
Panel PP-Statistic	-5.90138*	-3.0509*
Panel ADF-Statistic	-4.4329*	-2.8517*
Group rho-Statistic	-1.1329	-0.3114
Group PP-Statistic	-3.1161*	-2.5736*
Group ADF-Statistic	-1.8857**	-2.4648*

"*" and "**" denote the rejection of the null of no cointegration (Pedroni) at the 1%, 5% level of significance respectively. The variance ratio test is right-sided, while the rest are left-sided.

5.3 The EKC findings in China

Based on the results of unit root tests and cointegration tests, there exist strong long-run relationship between GDP per capita and two pollutants (sulphur dioxide and dust). However, there may not be conintegration between soot and GDP per capita, because the results of unit root tests show that the two series are not integrated in the same order. As a result, the analysis of the relationship between these two indicators is not included in this section.

The pollution-income curves for two pollutants can be procured by computing the quadratic or the cubic function. The appropriate model for each pollutant is cubic. The form of the model is:

$$\ln(\text{Emission}) = \alpha + \beta_1 \ln\text{GDP} + \beta_2[\ln\text{GDP}]^2 + \beta_3[\ln\text{GDP}]^3$$

Coefficients (β_1, β_2 andβ_3) are calculated in the within OLS estimator. The fitted curve for sulphur dioxide and dust is showed in Figure.6a and Figure.6b respectively. In the figure, y-axis indicates fitted value of emission and x-asis is per capita GDP.

According to the results of panel estimation, it is obvious that two curves are inverted N-shaped. The inverse N-shape shows that with the increase of economic growth (GDP per capita), emission of industrial SO_2 or industrial dust first decreases, then rises after the left turning point and when it past the right turning point it will decline at last. As we can see in the figure, the x-value of the left turning point for each pollutant is quite low. The GDP per capita of left turning point is about 1138 Yuan and 314 Yuan for industrial SO_2 and industrial dust respectively (in 1990's price level). And the GDP per capita of the right turning point is about 12200 Yuan and 4859 Yuan for industrial SO_2 and industrial dust respectively. For industrial dust, all provinces have reached the right turning point and are in the decline stage. According to provincial real per capita GDP (in 1990's price level), only eleven of the 29 provinces have surpassed the turning point in the SO_2- GDP curve while other provinces are in the rising stage (see Table.10). The turning points show that with the increase of economic growth industrial dust pollution decreased earlier than industrial SO_2.

One striking point is that the x-value of Dust-GDP's left turning point is quite low. Provincial GDP per capita is much more than its value (314 Yuan). For example, the poorest province Guizhou's per capita GDP in 1991 is 864 Yuan. In terms of the fact, the left decline part of Dust-GDP curve should be ignored. As a result, the relationship between dust emission and per capita can be characterized by inverted U-Curve.

(a) SO_2-GDP curve (b) Dust-GDP curve

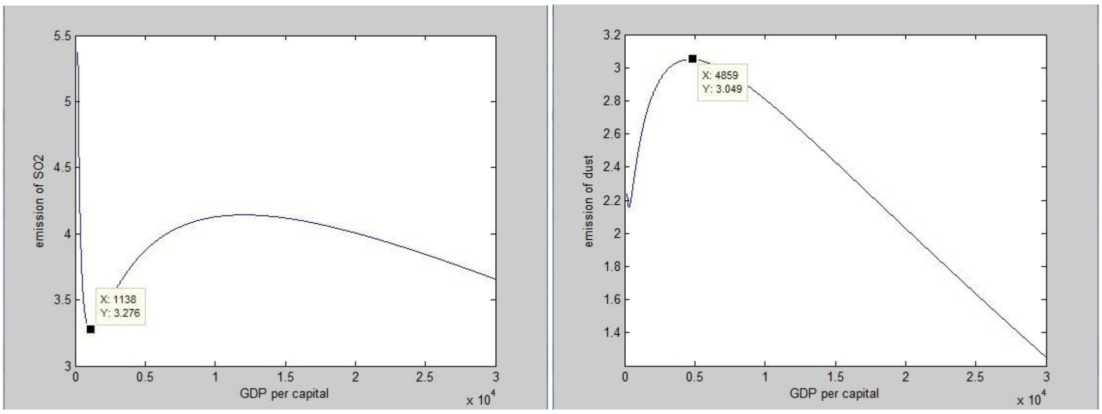


Figure.6. the fitted pollution-income relationship for two pollutants from OLS estimator

Table.10

Rising stage (1138-12200 Yuan)	Declining stage (> 12200 Yuan)
Hebei, Shanxi, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi, Hainan, Sichuan, Guizhou, Yunnan, Shanxi, Gansu, Qinghai, Ningxia, Xinjiang (18 provinces)	Bejing, Tianjin, Neimenggu, Liaoning, Jilin, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong (11 provinces)

6. Conclusion

The aim of this paper is to research the relationship between environmental degradation (or pollution) and economic growth in China and to test whether the relationship can be well characterized by EKC which is a inverted U-curve. Based on EKC hypothesis, this research focuses on three atmospheric pollutants, which have serious negative effects on human health, including industrial sulphur dioxide, industrial dust and industrial soot. While economic growth is represented by per capita GDP, environmental degradation or pollution is indicated by the emission of pollutant. Panel data approach is adopted in this research based on economic and environmental data of 29 provinces from 1991 to 2010.

Before running the panel estimation, several tests of model specifications are implemented. In accordance with the results of F test, Hausman test, model estimation and Wald test, a cubic logarithm model is appropriate to test the relationship between the emissions of three pollutants and per capita GDP. For industrial sulphur dioxide and soot, random effect model is used for panel data analysis, but fixed effect model is preferred for industrial dust.

After the model pre-specification, econometric methods are used to test if there is long-run relationship between emission and per capita GDP for three pollutants. Unit root tests are applied first and the results show that per capita GDP, sulphur dioxide and dust are integrated in order one, but series of soot are stationary in level. Then further cointegration tests are carried out. Cointegration results show that there conintegration between emission and per capita GDP for two pollutans (SO_2, dust). According to the panel estimation results from OLS estimator, the relationship between emission and per capita GDP is inverse N-shaped. However, dust-GDP relation can be considered as inverted U-shaped for the reason that per capita GDP of left turning point is too small (314 Yuan). In terms of turning points, dust stepped into the second declining stage earlier than sulphur dioxide. For industrial dust, all the provinces are in the stage of environmental improvement. However, only 11 provinces with high per capita GDP have reached the declining stage of environmental pollution in terms of industrial sulphur dioxide. With the growth of economy, SO_2 emission in each of the rest provinces is still on the rise. As a result, the government should adopt effective measures to optimize economic development model and protect environment.

There are limitations of this empirical study. First of all are the validity, reliability and lack of data. All the economic and environmental data are from China Statistical Yearbook. Due to the incomplete and not-transparent data system, official data from China Statistical Yearbook may be biased. Besides, as mentioned in Data Section, statistical standard and method changed during 1991-2010. Second, specific time effect is not included in the cubic model. As a result, a simple F-test is carried out. With specific time effect, the model will be more appropriate. Third, it should be careful to select one from OLS, FMOLS, and DOLS. However, OLS is used for testing the long-run conintegration relationship. Forth, national CPI is used to calculate real GDP for every province. But as a matter of fact, all the provinces were not in the same price level in a certain year. Fifth, only three atmospheric pollutants are studied. Sixth, emission of pollutant represents environmental indicator. Because of different provincial area, the same amount of pollution will harm the environment in different level. Concentration of pollutant is a more appropriate choice.

7. Reference

Ansuategi, A., Barbier, E., & Perrings, C. (1998). The environmental Kuznets curve. In *Theory and implementation of economic models for sustainable development* (pp. 139-164). Springer Netherlands.

Antweiler, W., Copeland, B.R. & Taylor, M.S. (2001).Is Free Trade Good for the Environment, *American Economic Review*, 91, 877-908.

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., ... & Dimentel, D. (1995). Economic growth, carrying capacity, and the environment. *Science(Washington)*, *268*(5210), 520-521.

Baltagi, B. (2005). *Econometric analysis of panel data*, Wiley. com. (electronic book)

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

Borghesi, S. (1999). The Environmental Kuznets Curve: a Survey of the Literature, *European University Institute*, Florence.

Boulding, K.E. (1966). The Economics of the Coming Spaceship Earth, In: Jarrett, H. (ED), *Environmental Quality in a Growing Economy*, Baltimore: Johns Hopkins Univ. Press, pp. 3-14.

Breitung, J. (2000). The Local Power of Some Unit Root Tests for Panel Data, *Advances in Econometrics*, 15, 161–177.

Chen, D., Li, L., & Wang, L.J. (2004). Empirical Study on Evolution of Hunan's Economic Growth and Environmental Quality, *Journal of Hunan Economic Management College*, vol. 15, no. 4, pp. 13-14. (Translation)

Chen, H.W. & Liu, K.B. (2004). Economic Growth and Environmental Quality: An Empirical Analysis of the Environmental Kuznets Curve, *Fudan Journal (Social Science)*, no. 2, pp. 87-94. (Translation)

Cole, M. A. (2004). Trade, the Pollution Haven Hypothesis and the Environmental Kuznets Curve: Examining the Linkages, *Ecological Economics*, vol. 48, iss.1, pp. 71-81.

Copeland, B.R. (1996). Pollution Content Tariffs, Environmental Rent Shifting, and the Control of Cross-border Pollution, *Journal of International Economics*, vol. 40, pp. 459– 476.

de Bruyn, S.M. (1997). Explaining the Environmental Kuznets Curve：Structural Change and International Agreements in Reducing Surlphur Emission, *Environment and Development Economics*, vol. 2, iss.4, pp. 485-503.

Dinda, S. (2004). Environmental Kuznets Curve Hypothesis: A Survey, *Ecological Economics*, (49): 431 – 455.

Ding, J.H. & Nian, Y. (2010). The Investigation of Economic Growth and Environmental Pollution – Illustrated by the Case of Jiangsu Province, *Nankai Economic Studies*, no. 2, pp. 64-79. (Translation)

Egli, H. (2001). "Are Cross-Country Studies of the Environmental Kuznets Curve Misleading? New Evidence from Time Series Data for Germany", Discussion Paper 10/2001, Ernst-Moritz-Arndt University of Greifswald.

Friedl, B. & Getzner, M. (2003). Determinants of CO2 Emissions in a Small Open Economy, *Ecological Economics*, vol. 45, iss.1, pp. 133-148.

Fu, M. (2008). Chinese Environmental Kuznets Curve: Shapes, Turning Points and Responsible Factors, *Quantitative and Technical Economics*, no. 11, pp. 40-54. (Translation)

Grossman, G. M. and Krueger, A. B. (1991). Environmental impacts of the North American Free Trade Agreement, NBER, working paper, No. 3914.

Grossman, G.M. & Krueger, A.B. (1992). Environmental Impact of a North American Free Trade Agreement, Princeton University Woodrow Wilson School of Public and International Affairs, pp. 401-411.

Grossman, G.M. & Krueger, A.B. (1995). Economic Growth and Environment, *Quarterly Journal of Economic*, no. 2, pp. 353-377.

Guo, J.H. & Li, B.Y. (2010). A Co-integration Analysis of China's Economy Development and Environmental Pollution – Based on the Provincial Panel Data from 1991 to 2007, *Application of Statistics and Management*, vol. 29, no. 2, pp. 281-293. (Translation)

Hamilton, C. & Turton, H. (2002). Determinants of Emissions Growth in OECD Countries, *Energy Policy*, vol. 30, iss.1, pp. 63-71.

Hettige et al. 2000 (2000). Industrial Pollution in Economic Development：The Environmental Kuznets Curve Revisited, *Journal of Development Economics*, vol. 62, iss.2, pp. 445-476.

Hilton, F.G.H. & Levinson, A.M. (1998). Factoring the Environmental Kuznets Curve：Evidence from Automotive Lead Emission, *Journal of Public Economics and Management*, vol. 35, iss.2, pp. 126-141.

Holtz-Eakin, D. & Selden, T.M. (1995). Stoking the Fires? CO2 Emissions and Economic Growth, vol. 57, iss.1, pp. 85-101.

Huang, Y.J. (2005). Empirical Research of Shenzhen on Economic Development and Environmental Quality, *Guangdong Science and Technology*, no. 12, pp. 37-38. (Translation)

Im, K.S., Pesaran M.H. and Shin Y. (2003). "Testing for Unit Roots in Heterogeneous Panels", *Journal of Econometrics*, 115, 53–74.

Krenz, A. (2012). A Panel Co-integration Analysis of Industrial and Services Sectors' Agglomeration in the European Union, *Center for European, Governance and Economic Development Research Discussion Paper*, (146).

Kaufmann, R.K., Brynhildur, D., Sophie, G. & Peter, P. (1998). The Determinants of Atmospheric SO2 Concentration: Reconsidering the Environmental Kuznets Curve, *Ecological Economics*, vol. 25, iss.2, pp. 209-220.

Levin, A., Lin C.F. and Chu C. (2002). Unit root test in panel data: Asymptotic and finite sample properties, *Journal of Econometrics*, 108, 1–25.

Liang, L.T. (2008). The Relationship between Economic Growth and Environmental Quality – A Case Study of Jiangsu Province, *Journal of Nanjing Agricultural University (Social Science Edition)*, vol. 8, no. 1, pp. 20-25. (Translation)

Li, D. & Wang, C.X. (2007). Panel Data Analysis on the Relationship between Economic Growth and Air Pollution in China, *Finance and Economics*, no. 2, pp. 43-50. (Translation)

Li, G.Z., Li, C.X., & Xun, Y.H. (2005). Relationship between Economic Development and Environmental Pollution in Hebei, *Statistics and Decision*, no. 9, pp. 94-95. (Translation)

Ling, K., Wang, H.C. & Liu, T. (2001). The Statistical Research on the Relationship between Urban Economic Development and Environmental Pollution: the Case of Nanjing, *Statistical Research*, no. 10, pp. 46-52. (Translation)

Maddala, G.S. and Wu S. (1999). A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test, *Oxford Bulletin of Economics and Statistics*, 61, 631–652.

Ma, S.C. & Li, G.Z. (2006). The Kuznets Curve of Relationship between Economic Growth and Environmental Pollution, *Statistical Research*, no. 8, pp. 37-40. (Translation)

Ma, Y. & Zhu, X.D. (2007). Study on Environmental Effects of Economic Development in Jiangsu Province Based on Environmental Kuznets Curve, *Environmental Science and Management*, no. 4, pp. 38-42. (Translation)

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (1972). The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind, Universe Books. *New York*.

Mu, H.L. (2008). Analysis of Beijing's Environmental Kuznets Curve, *Journal of Ecological Economy*, no. 1, pp. 366-368. (Translation)

Panayotou, T. (1993). Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development, Working Paper WP238, Technology and Employment Programme, International Labour Office, Geneva.

Panayotou, T. (2000). Economic Growth and the Environment, Center for International Development, Harvard University, CID Working PaperNo.56.

Peng, S.J. & Bao, Q. (2006a). Economic Growth and Environmental Pollution: An Empirical Test for the Environmental Kuznets Curve Hypothesis in China, *Research on Finance and Economics*, no. 8, pp. 3-17. (Translation)

Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and statistics*,*61*(S1), 653-670.

Pedroni, P. (2000). Fully Modified OLS for Heterogeneous Cointegrated Panels, *Advances in Econometrics*, 15, 93–130.

Peng, S.J. & Bao, Q. (2006b). Economic Growth and Environmental Pollution-Based on Simultaneous Equations and Panel Data, *World Economy*, no. 11, pp. 48-58. (Translation)

Qiu, F.D. & Gu, Y.H. (2006). Research on the Mechanism of Interaction between Environment and Economy in Xuzhou, *Economic Geography*, no. 6, pp. 22-26. (Translation)

Selden, T. and Song, D. (1994). Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions?, *Journal of Environmental Economics and management*, vol. 27, iss.2, pp. 147-162.

Selden, T.M., Forrest, A.S. & Lockhart, J.E. (1999). Analyzing Reductions in US Air Pollution Emission：1970 to 1990, *Land Economics*, vol. 75, iss.1, pp. 1-21

Selden, T.M. & Song, D. (1994). Environmental Quality and Development: Is There A Kuznets Curve for Air Pollution Emissions?, *Journal of Environmental Economics and Management*, vol. 27, iss.2, pp. 147-162.

Shafik, N., & Bandyopadhyay, S. (1992). Economic Growth and Environmental Quality: Time Series and Crosscountry Evidence, Background Paper for the World Development Report 1992, World Bank, Washington, DC.

Shafik, N. (1994). Economic Development and Environmental Quality: An Econometric Analysis, *Oxford Economic Papers*, vol. 46, iss.4, pp. 757-773.

Shen, F. (2008). The Relation between Economic Growth and Environment Pollution in Shanghai, *Journal of Finance and Economics*, no. 9, pp. 81-91. (Translation)

Song, T., Zheng, T. & Tong, L. (2008). An Empirical Test of the Environmental Kuznets Curve in China: A Panel Cointegration Approach, *China Economic Review*, 19, pp. 381-392.

Stern, D. I. (1998). Progress on the Environmental Kuznets Curve, *Environment and Development Economics*, vol.3, 173–196.

Stern, D.I. (2002). Expaining Changes in Global Sulfur Emissions：An Econometric Decomposition Approach, *Ecological Economics*, vol. 42, pp. 201-220.

Stern D.I., Common M.S., & Barbier E.B. (1994). Economic Growth and Environmental Degradation: A Critique of the Environmental Kuznets Curve, Discussion Papers in Environmental Economics and Environmental Management 9409, EEEM, University of York, York.

Stern, D. I., Common, M. S., & Barbier, E. B. (1996). Economic Growth and Environmental Degradation: The environmental Kuznets Curve and Sustainable Development, *World Development*, 24, 1151–1160.

Sun, A.C. (2006). Research on the Relationship between Economic Development and Environmental Pollution in Qinhai, *Economists*, no. 2, pp. 271-272. (Translation)

Viguier, L. (1999). Emissions of SO2，NOx，and CO2 in Transition Economies：Emission Inventories and Divisia Index Analysis, *Energy Journal*, vol. 20, iss.2, pp. 59-87.

Vincent, J. (1997). Testing for Environmental Kuznets Curves with in a developing country, *Environment and Developmental Economics*, vol. 2, iss.4, pp. 417-431.

Wang, H.J., Gan, S.J., & Li, S.T. (1999). Sustainable Development and Economic Structure, Beijing: Economic Science Press. (Translation)

Wang, Y.H., Cui, X., & Chen, W. (2006). Empirical Research on the Relationship between Economic Growth and Environmental Degradation in Nanjing, *Resources and Environmental in the Yangtze Basin*, vol. 15, no. 2, pp. 142-146. (Translation)

World Bank. 1992. World Development Report 1992, Oxford University Press, New York, USA.

Wu, Y.P., Dong, S.C. & Song, J.F. (2002). Modeling Economic Growth and Environmental Degradation of Beijing, *Geographic Research*, no. 2, pp. 239-246. (Translation)

Xu, L.H. & Wang, L.B. (2007). Analysis of the Environmental Kuznets Curve Characteristics of Industrial Waste in Jinan, *Shandong Science*, no. 2, pp. 72-75. (Translation)

Yang, H.S., Jia, J. & Zhou, Y.Z., & Wang, S.G. (2005). Impact on EKC by Trade and FDI in China, *China Population* and Environment, vol. 15, no. 3, pp. 99-103. (Translation)

Yu, F. & Qi, J.G. (2006). Empirical Analysis on Impact of Economic Development and Environmental Quality-Based on the Panel Data of Chinese Provinces and Municipal cities from 1999 to 2004, *China Industrial Economy*, no. 8, pp. 36-44. (Translation)

Zhang, J. & Zhang, Y.M. (2006). Environmental Kuznets Curve in Guangdong and Its Determinants, *Guangdong Social Science*, no. 3, pp. 17-22. (Translation)

Zhang, X. (1999). Overall Evaluation of China's Environmental Policies, Beijing: CASS, vol. 3. (Translation)

Zhang, Z. (2000). Decoupling China's Carbon Emissions Increase from Economic Growth：An Economic Analysis and Policy Implications, *World Development*, vol. 28, iss.2, pp. 739-752.

Zhou, S., Zhang, J., Ge, J. & Wang, C. (2010). The Relationship between Economic Growth and Air Pollution in Jiangsu Province: Based on an Empirical Analysis of Indulstriy Panel Data, *Jiangsu Social Science*, no. 4, pp. 227-232. (Translation)

8. Appendix

1. Data of Bejing (as an example)

OBS	SO_2*	DUST*	SOOT*	RGDP/P**	$LNSO_2$	LNDUST	LNSOOT	LNGDP/P
BJ-1991	21	7	10	5609.446	3.044522	1.94591	2.302585	8.632207
BJ-1992	20.0191	7.7162	10.5466	6377.081	2.996687	2.043322	2.355804	8.760466
BJ-1993	20.3736	6.4446	10.9402	7055.233	3.01424	1.863243	2.392444	8.861525
BJ-1994	17.5616	5.8903	12.6453	7875.434	2.865715	1.773307	2.537286	8.971504
BJ-1995	21.4899	6.2609	12.4471	7855.701	3.067583	1.834324	2.521488	8.968995
BJ-1996	21.2283	5.7541	11.0747	7548.427	3.055335	1.749913	2.404663	8.929094
BJ-1997	21.0827	6.9076	9.4663	8119.671	3.048453	1.932622	2.247738	9.002045
BJ-1998	19.2917	9.5319	8.3408	9091.078	2.959675	2.254644	2.121159	9.115049
BJ-1999	16.1674	10.0235	5.6345	10261.47	2.782997	2.304932	1.728908	9.236151
BJ-2000	14.6431	9.3681	5.1842	11733.51	2.683969	2.23731	1.645616	9.370204
BJ-2001	12.6309	6.2679	4.3826	13099.02	2.536146	1.835441	1.477642	9.480293
BJ-2002	12.0556	4.6471	3.308	14855.71	2.489529	1.536243	1.196344	9.606139
BJ-2003	11.4012	3.2145	2.9218	16937.3	2.433719	1.167672	1.0722	9.737273
BJ-2004	12.5	3.6	2.9	19722.33	2.525729	1.280934	1.064711	9.889507
BJ-2005	10.5	3.3	1.8	21245.61	2.351375	1.193922	0.587787	9.963906
BJ-2006	9.4	3	1.5	23615.19	2.24071	1.098612	0.405465	10.06965
BJ-2007	8.3	1.9	2.1	27397.13	2.116256	0.641854	0.741937	10.21819
BJ-2008	5.8	1.5	2	28512.19	1.757858	0.405465	0.693147	10.25809
BJ-2009	6	1.7	1.9	28406.46	1.791759	0.530628	0.641854	10.25437
BJ-2010	5.7	1.7	2.1	30837.21	1.740466	0.530628	0.741937	10.33648

*in 10000 tons

**in Chinese Yuan, price level of 1990

2. Descriptive statistics

	SO2	DUST	SOOT	GDP/P
Mean	56.38448	25.66569	28.40293	5932.234
Median	47.3	20.1	24.7	4067.55
Maximum	183.3	100.6	131.4	32060.2
Minimum	1	0.7	0.7	863.6
Std. Dev.	40.5184	20.68826	20.77028	5459.743
Skewness	0.911617	1.149438	1.135044	2.265605
Kurtosis	3.175629	3.954446	4.723902	8.949464
Jarque-Bera	81.07981	149.7318	196.3575	1351.593
Probability	0	0	0	0
Sum	32703	14886.1	16473.7	3440696
Sum Sq. Dev.	950568	247814.4	249783.2	1.73E+10
Observations	580	580	580	580
Cross sections	29	29	29	29

*in 10000 tons

**in Chinese Yuan, price level of 1990

3. Inflation, consumer price (annual 1%)

1990	18.33304		
1991	3.058311	2001	0.255305
1992	3.543575	2002	0.722903
1993	6.340345	2003	-0.76595
1994	14.58327	2004	1.15591
1995	24.23709	2005	3.884183
1996	16.89706	2006	1.821648
1997	8.324015	2007	1.463189
1998	2.806843	2008	4.750297
1999	-0.84463	2009	5.864384
2000	-1.40789	2010	-0.70295

Source: world Bank database