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RELATIONSHIP BETWEEN POLLUTION AND ECONOMIC GROWTH IN CHINA: EMPIRICAL EVIDENCE FROM 111 CITIES

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Abstract: Steady economic growth and environmental protection are two contradictory goals of top priorities in China 2016–2020 Planning Project. Cities play important role in economic and environmental development. The research on cities' economic-pollution relationship is vital to the choices in city developing patterns. This paper investigates the relationship between economic growth and environmental pollution of 111 Chinese prefectural-level cities in the period 2004–2012 and how it might influence the choice of a city's developing pattern. These 111 cities are classified into five different clusters, one of which has particular pollution-economic relationship and some of which coordinate the EKC theory. The paper suggests that city features, scale effect and composition effect are important in the distribution of cities' developing patterns.

Keywords: Environmental pollution; economic growth; random effect regression model; developing patterns

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INTRODUCTION

It has always been a dilemma for policy makers to balance between environment security and economic growth. As is with the Environmental Kuznets Curve (EKC) theory, the common view is that in the early stage of industrialization, economic growth is usually accompanied by environmental degradation, but eventually with environmental improvement in the stage of clean economy. Now many developed countries has entered the stage of clean economies (Grossman & Krueger, 1993) while most developing countries are still experiencing the simultaneous increment of income and pollution.

China, the world's largest developing country, has its economy continuously boomed ever since the 21st century and its total GDP ranked second in 2010, and reached the first in 2014 (World bank, 2014). However, China also suffers serious environmental pollution. For example, ambient air quality in 17% of cities is below the national standards of China (Kan *et al.*, 2012) while the number amounts to 75% in urban places (Shao *et al.*, 2006). So what is the income-emission relationship in China? Many researchers have studied this issue, such as Diao X.D. *et al.* (2009), Gao *et al.* (2012) and Mao *et al.* (2013). Shen (2006) and Bao *et al.* (2006) showed that the EKC can be derived under careful selection of pollution index and models, as also conducted by Du *et al.* (2010) and Zhou (2011). Wang *et al.* (2010) found that the leading factor to such difference is geographical factors.

However, there are two main drawbacks in the previous econometric analysis, that is, the overemphasis of standard EKC function (Stern, 2004) and the omission of the city-level evidence (Diao X.D. *et al.*,2009; Mao *et al.*, 2013). Theses drawbacks can be settled by random effect models, which verifies the different developing patterns in cities of China, and by cluster analysis, which detects the unique income-emission relationships of different clusters after controlling scale effect and composition effect. Our paper confirms the existence of unobserved city effect and finds out the most environmental-friendly developing mode.

Income-emission relationship is a major concern for both academics and policy-makers. Numerous methods have been proposed to set up the income-emission relationship model, such as the EKC curve. Below, we will present a brief review of the EKC curve, which is firstly proposed by Grossman and Krueger in 1991 when they analyzed the potential environmental benefits of the North American Free Trade Agreement (NAFTA). According to them, economic growth, rather than a threat, will lead to environmental improvement, and the turning point appears in the high stage of income level (USD 5000–8000). Such non-linear conclusion has been largely accepted by early economists (e.g. Meadows *et al.*, 1972; Panayotou, 1993). In a study with panel data of GDP per capita and air pollutants, Selden & Song (1994), too, has a similar but more conservative conclusion that the reduction of emissions will occur, but only in a very long period of time.

Traditionally, few factors shape the EKC: (1) rising demand for better environmental quality and the changing of the income elasticity of demand of environment amenities (Beckerman,1992; Selden & Song, 1994; Carson *et al.*, 1997); (2) scale effect, composition effect and technological effect that affect environmental qualities (Grossman and Kruegar, 1991; Stern, 2004); (3) international trade has caused environmental quality largely region-related (Dinda, 2004); (4) the negative externalities of pollution can be internalized under free markets (Zhong *et al.*, 2010), and better improved with economic growth (Kadekodi & Agarwal, 1999); (5) government regulations or policies are regarded by some economists as the dominating reason for the decline part of EKC (Deacon, 1994; Dasgupta *et al.*, 2002). This paper will examine the scale effect and composition effect with empirical analysis.

Other environmental economists, however, cast doubt on the EKC and the empirical techniques that the EKC is derived from (Dasgupta *et al.*, 2002; Stern, 2004). Globalization, for example, may preclude the declination of environmental pollution and thus adjust the Curve to 'race to the bottom', and the potential 'new toxics' induced in the industrialization are likely to uplift it. Luckily neither is supported by present evidence. Egli (2004) further questioned the existence of EKC in scope of one single nation. The 'revised EKC' appears in much recent research, suggesting that the pollution can drop even at a low level of income per capita. Our paper partly supports such finding.

Two methods are popular in the analysis of the interactions between environmental pollution and economic efficiency: econometric methods and decomposition models, briefly summarized below (for details, see the original sources). Grossman *et al.* (1994) and de Bruyn (1997) proposed decomposition models of emissions intensity and GDP, which was further adjusted by Hamilton & Turton (2002) with fuel and energy consumption data. These two models can be directly applied to the research on scale effect and composition effect. The structural models can better provide a complete picture of pollution system (Nordhaus, 2010), but suffer from the lack of robustness and data sets (Liao & Cao, 2013).

On the other hand, the EKC can be derived from econometric framework (Stokey, 1998; Dinda, 2004).

Usually the function forms are linear, quadratic and cubic polynomial, and recently a more flexible model, linear spline model, is employed (Liao *et al.*, 2013). Models of quadratic function directly show the 'turning point' of income level, where emissions or concentrations are at peak. Based on such models, studies with panel multi-countries data and various pollutants data lead to diversified results. Particulate matters and emissions of SO_2 and CO generally reveal the inverted-U relationship with income, but emissions of CO_2 either monotonically change or display 'N' shape patterns. Building on previous studies, this paper applied a random effect model to further detect the relationship of economic growth and industrial pollution. Under hierarchical cluster analysis, we find that the both the amount and dynamic patterns of pollution vary in cities due to the unobserved city effect.

The remainder of this paper is organized as follows. In Section 2, we describe the data sets we employed and conduct statistical analysis. In Section 3, we show the empirical results based both on econometric and statistical methods, and examine the possible outcomes. And in Section 4 we present our conclusions and policy implications.

DATA

The data, on the total city level, is extracted from China City Statistical Yearbook 2004–2012 and covers the same 111 prefectural-level cities each year (Year 2012: without Guangzhou). The selection of these 111 cities is based on the studies of urban low carbon development evaluation index system (See Zhu & Liang, 2012). These 111 cities are geographically randomly selected and thus their levels of economic development are randomly distributed. Detailed information can be found in **Table A1** (**Table A1–A3** and **Fig. A1** are omitted. If readers have any questions with regard to the data and results, please do not hesitate to contact us).

We use GDP, GDP per capita, proportion of secondary and tertiary industry GDP as the economic covariates, and industrial waste water discharge, SO_2 emission and industrial soot (dust) emission as the pollution covariates (**Table 1**). Our paper replaces income per capita with GDP per capita for the following three reasons: (1) income per capita data in China is not released officially until 2014; (2) GDP per capita has a positive relationship with income per capita, which especially matches China's economies since 2003; (3) some researchers have successfully adopted GDP per capita to depict economic growth, As for pollutants, there are mainly three kinds: air pollutants, solid waste pollutants and water pollutants (Guo *et al.*, 2010). Our paper only investigates air pollutants and water pollutants because of data availability, and the certain differential effects of certain pollutants on economies (Stern, 2004).

We used methods of mean completer to handle missing values, and deleted data that does not have data in adjacent years, and finally got 998 matched data sets. **Table 1** gives the definition of variables and their descriptive statistics. Industrial pollution index (var) refers to the normalized 0–1 pollution value after identically weighting the three pollution covariates.

Data sets description

Table 2 depicts data of GDP per capita and industrial pollution index on the timely basis. According to the data collected, GDP per capita rises at a constant high speed, with an annual growth rate of 13.55%. Industrial pollution index, on the other hand, fluctuates. It descends from year 2005 to 2009, which matches Mao *et al.* (2013) research. The rise of pollution index in 2010 may result from the increment of proportion of secondary industrial GDP.

Five typical cities (Beijing, Zhuhai, Nanchang, Baoding and Karamay, representatives of the five clusters under hierarchical cluster analysis in later sections) are selected to demonstrate how the significantly varied values of industrial pollution index change with time (**Fig. 1**). Beijing's amount of pollution keeps dropping, Nanchang and Karamay's amount of pollution rise at different levels, Zhuhai's pollution index displays inverted-U relationship across time and Baoding's industrial pollution fluctuates.

Figure 2 displays the income-pollution relationship in mean values and in city-level values (998 data sets). **Figure 2a** shows that, unlike the EKC theory, industrial pollution experiences cyclic increasing and decreasing along with economic growth. However, we can hardly arrive at the similar conclusion if we take a look at **Fig. 2b**. Most data is plotted at the left side of the figure, implying that the different undetected relationships overlap with each other due to: (1) the cities' unique developing patterns; (2) unique city effect; (3) scale and composition effect. Thus the data requires further application with controlled variables or cluster analysis and in Section 3 we will investigate the income-pollution relationship with the revised econometric function.

The data has two drawbacks. The first is that we have omitted solid waste pollutants and that the 9-year time span is comparatively short (List & Gallet, 1999; Stern & Common, 2001). The second is that we have not deflated the nominal GDP.

Table 1. Variables and descriptive statistics

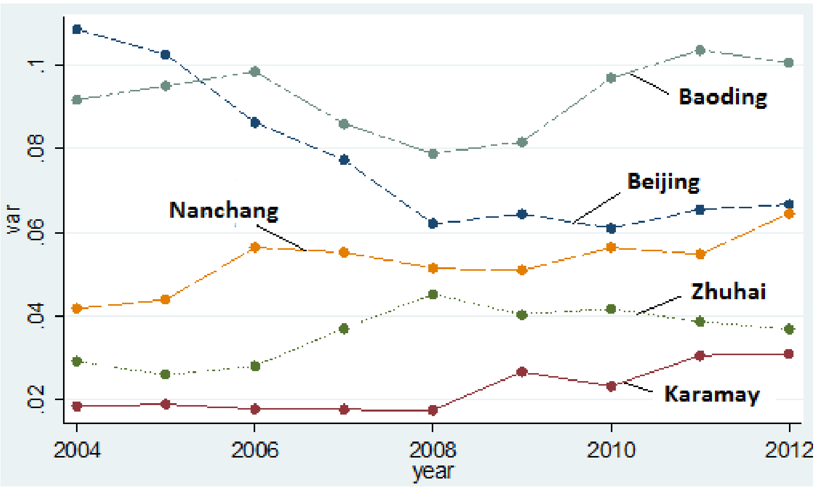
ariable	Definition	Observations	Descriptive Statistics			
			Mean	Std. Dev.	Min	Max
GDP	GDP	998	2.08e+07	2.44e+07	482348	2.02e+08
aGDP	GDP per capita	998	36 512.62	23 857.75	4919	142 067
second	proportion of secondary industrial GDP	998	52.02	10.88	20.60	90.97
third	proportion of tertiary industrial GDP	998	38.74	10.25	8.58	76.07
soot	industrial soot (dust) emission	998	42 281.49	195 118.6	5.3765	5168 812
water	industrial waste 25áter discharge	998	11 672.5	12 993.75	17	85 347
SO_2	SO2 emission	998	90 304.13	77 554.01	0	683 162
var	Industrial pollution index	998	0.092	0.080	0.000 0311	0.672 979

Source: China City Statistical Yearbook 2004–2012

Table 2. Mean values of aGDP, var and second

Variable	2004	2005	2006	2007	2008	2009	2010	2011	2012
aGDP	20 403.77	22 810.19	26 370.34	31 057.42	36 140.13	39 222.08	45 006.96	51 373.79	56 408.15
var	0.094 086	0.098 926	0.096 682	0.095 204	0.089 655	0.085 845	0.086 245	0.094 421	0.089 352
second	36.90	38.95	38.60	38.41	37.92	40.05	39.40	38.95	39.48

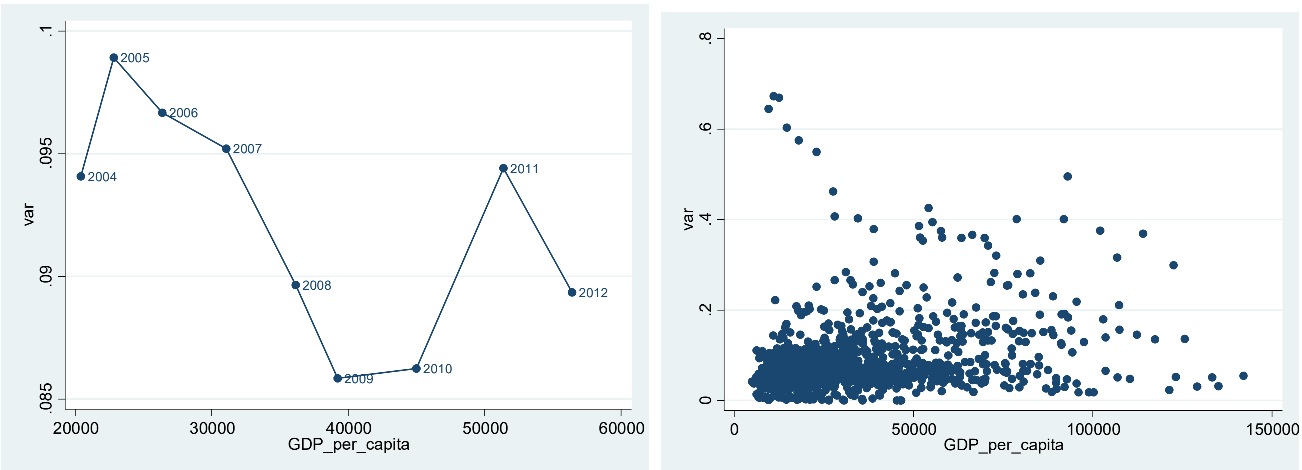
Source: China City Statistical Yearbook 2004–2012



Values for industrial pollution index changes with time

Fig. 1 Industrial pollution index

Source: China City Statistical Yearbook 2004–2012



a Mean values b 998 data sets

Fig. 2 GDP per capita-pollution relationship

Source: China City Statistical Yearbook 2004–2012

Table 3 Features of the five clusters

Cluster	Economic Mode	Industrial Composition	Typical Cities
First Cluster	High income, steadily and high growing rate	Well developed tertiary industry	Beijing, Shanghai, Shenzhen
Second Cluster	Medium-high income, fluctuating	Steadily growing tertiary industry	Zhuhai, Zhongshan
Third Cluster	Medium-low income, late-development advantage	Stable, dominating secondary industry	Nanchang, Anshan, Chanchun
Fourth Cluster	Low income, low growth rate	Fluctuating dominating industry	Baoding, Yibin, Pingdingshan
Fifth Cluster	Resource-oriented	Dominating secondary industry	Daqing, Karamay

Source: China City Statistical Yearbook 2004–2012

ECONOMETRIC MODEL

We apply random effect model due to the Hausman test. Taking into account the heteroskedasticity of industrial pollution index, we introduced unobserved city effect into the model. Adding time trends in GDP, we have:

$$\ln(\mathrm{var}_{it}) = \beta_0 + \beta_4 \ln(\mathrm{aGDP}_{it}) + a_i + \mathrm{GDP}_t + \varepsilon_{it} \quad (1)$$

where var_{it} and aGDP_{it} represent industrial pollution index and GDP per capita of city i in year t, GDP_t represents GDP in year t, and a_i is the unobservable effect of city i. **Table A2** gives the results, where the impact of GDP per capita remains insignificant to pollution ($p = 0.2219$). Almost all city effects play significant roles, and almost all time factors are insignificant, suggesting the presence of impacts of unobserved city effect and time factors. Owing to the city effect, such results further indicate that so complex is the income-pollution relationship that the impact of GDP per capita on pollution cannot be fully detected using unclassified data sets. That is to say, the overlapped relationship between scattered GDP per capita and industrial pollution can only be revealed with careful classification, which matches the result in Section 2.

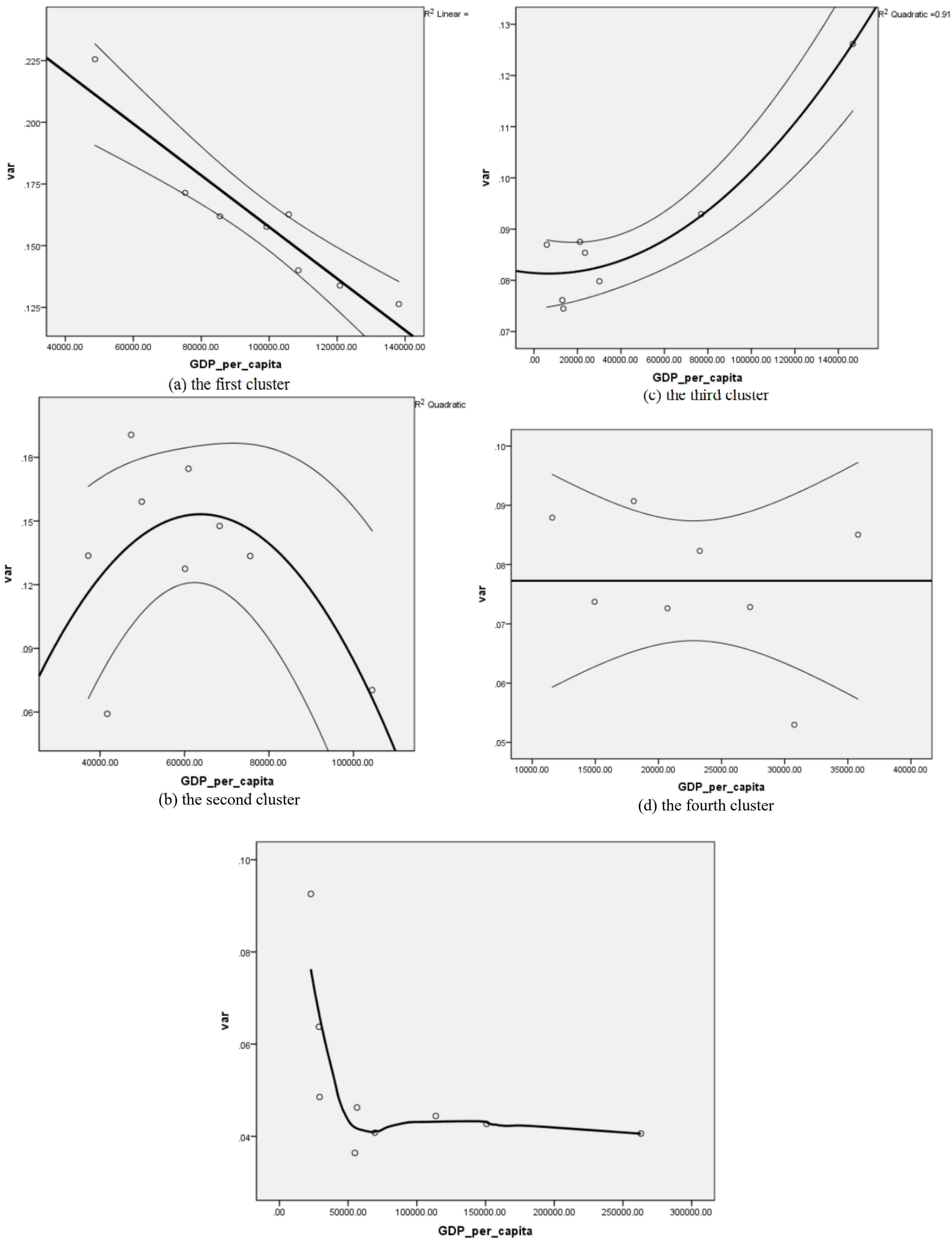
Empirical results of income-pollution relationship

As mentioned, there is no significant conclusion if we studied the relationship on the country-level. Thus we conducted hierarchical cluster analysis, using four economics variables (GDP, GDP per capita, proportions of secondary and tertiary industrial GDP). The cities are then divided into five clusters after Z-score standardization and cluster methods of ward's method. For better illustration, we inverted the cities of the fourth and fifth clusters in year 2005.

Table 3 and **Figure A1** present the characteristics of the four economic variables in five clusters respectively. The cities of the first cluster enjoy high income, with an annual growth rate constantly at 20.39%, and highly developed tertiary industry whose proportion remains approximately 56%. The amount of GDP is more than CNY 10 million through year 2004 to 2012. The second cluster is a group of medium-high income with frequent and tremendous fluctuation and the tertiary industry has steadily increased by 10%. The industrial composition of the third cluster is relatively stable, where the secondary industry, with an proportion of 50%, is dominant. GDP per capita of this group has a late-development advantage that it doubled its amount in the last two years. The cities in the fourth cluster have characteristics of low income and low growth rate (15.15%), with fluctuating industrial composition. Cities in the fifth cluster are resource-oriented ones and their development largely depends on the secondary industry (80% of total GDP).

We investigated the relationships between pollution and economic growth on cluster-level using mean GDP per capita as the core economic variable and industrial pollution index as the pollution variable. In **Figure 3**, we plotted the mean (focus) income-pollution data for each cluster. The linear fit lines are indicated by the darker solid lines in **Fig. 3a-d**, and the other two shallow solid lines in each figure represent conventional mean confidence intervals for the fit lines. In **Figure 3e**, we adopted method 'loess' with tricube kernel and 50% of points to fit due to data complexity. The fit line of **Fig. 3e** is indicated by the darker solid line.

It is obvious that the pollution in the first cluster is monotonically negative related with GDP per capita, which means that, the industrial pollution continues to drop with economic growth and such relationship remains stable. The relationship in the second cluster resembles to the EKC findings and the turning point of GDP per capita appears at CNY 65 000. The scale pollution of the second cluster is lower than that of the first cluster. For example, when GDP per capita reaches CNY 100 000, the pollution index is 0.09 in the second cluster while the index goes up to 0.16 in the first cluster. The pollution monotonically increases as GDP per capita grows in the third cluster; the pollution of the fourth cluster is not significantly relevant with GDP per capita. And in the fifth cluster, we find that the pollution firstly experiences a sharp decrease with economic growth and then maintains at a low level (0.04).



(a) the first cluster

(c) the third cluster

(b) the second cluster

(d) the fourth cluster

(e) the fifth cluster

Fig. 3 Income-pollution relationships

Source: China City Statistical Yearbook 2004–2012

These results indicates that the amount of pollution is different among clusters even if given certain levels of GDP per capita and that the amount of overall pollution level decreases from the first cluster to the fifth cluster. More intriguing, the income-pollution relationship is distinct in each cluster. Apparently, it is not that the five clusters of China are following the same fixed income-pollution relationship. Nor is it that there is one and only pattern that can be decomposed to certain different stages of economic development or different cross-sectional time, and the pattern of each cluster is part of the overall pattern.

Actually, with different pollution level at the same amount of GDP per capita, each cluster has its unique and decisive developing pattern (e.g. unobserved city effect) and thus creates its unique dynamic income-pollution interactions. This is the first conclusion in our paper. This conclusion is not consistent with multi-countries findings conducted by many researchers (Panayotou, 1993; Stern & Common, 2001) using multi-countries panel data, which means that we does not support the hypothesis that some districts with low income shapes the initial stage of EKC, some are approaching towards the peak and some high-income areas produce the falling part of EKC in China.

According to Beckerman (1992), the fundamental way to improve environmental conditions for a country is to become rich in the long-term (Lu Y., 2012). The five clusters, however, do not support such finding. As for the first cluster with the highest level of income and proportion of tertiary industry, it perfectly matches it, while the results of the third cluster are close to the theory of Meadows *et al.* (1972), which said that economic growth, to some extent, inhibits environmental improvement.

We now analyze these clusters in detail. In the first cluster, the proportion of tertiary industry, always higher than that of secondary industry, increases by 10% and reaches 62% in year 2012. GDP per capita exceeds USD 11 170 (USD at constant prices in year 2005) in year 2006 and finally reaches USD 23 000 in year 2012. With industrialization realized and the high-pollution economy converted to the clean service economy, the first cluster has the characteristics similar to that of service economy and its pollution has a monotonic decrement with economic growth since the citizens and policy-makers of this economy has more motivations to improve the living and ecological environment condition. The government at this certain stage is more likely to develop the latter one when facing trade-offs between economic growth and environmental protection. Upon spontaneous awareness or passively acceptance to signals of environmental degradation, the government is to take ex-ante actions, such as the usage of innovative technology, to improve the energy efficiency and lower the pollution in the production process. Ex-post actions are promulgations of environmental policies, introductions of smart technologies into environmental management or improvement, and applications of internalized markets. For example, Capital Steel Group (Corp.) was moved out of Beijing in 2005; Beijing and Shenzhen conducted environmental performance assessment pilot for quoted companies; systems of ecological demonstrative regions and green buildings (carefully designed with environmental protective technologies and construction simulations) are largely in use since the 21st century in well developed cities of China.

As for the third cluster with late-development advantage, it experienced a drop in the proportion of primary industry, which is lower than 10% since 2007, and a rise both in the proportions of secondary and tertiary industry but the proportion of secondary industry still maintains 7% higher than that of tertiary industry. In this middle and late stage of industrialization with increasing pollution and scarcer resource, the pollution of the third cluster in our paper is contradictorily relatively mild, with industrial pollution index at 0.07–0.09, which provides little evidence to the prediction that citizens are unwilling to enjoy natural amenities beyond material lives and are more willing to accept environmental deterioration, which to them is common negative externalities of economic growth (Arrow *et al.*, 1995). The possible explanations are (1) the trade without barriers with cities in well developed clusters, and (2) the intergenerational pollution has not yet spread out.

In the early stage of industrialization, an inverted-U curve can be found in the relationship between industrial pollution and GDP per capita in the second cluster. Similar circumstances occur in the fifth cluster where the pollution drastically decreases in the relatively low level of economy. A possible reason for this is that the governments in the fifth cluster show outstanding capacity in designs of policies and institutions, which help lower the risks of environmental degradation at a lower income level (Panayotou, 1997). For example, governments of cities like Daqing and Datong have conducted sustainable policies and actions to promote the efficiency of economic transformation, which revises the EKC to drop in advance.

In conclusion, there is no empirical evidence to support the prediction that cities (or clusters) in China are following one and only income-pollution relationship. On the other hand, Lopez (1994) has found different interactions using different pollutants and Arrow *et al.* (1995) has concluded that the inverted-U curve can only be applicable to less diffusive pollutant in short terms but not to concentrations or diffusive pollutants like CO_2 (Shafik & Bandyopadhyay, 1992).

This paper further shows that even with the same pollution index, the amount and trends of pollution varies across cities due to the unobservable city effect.

Influence factors of city's income-pollution relationship

To test on the hypothesis that each cluster has its unique income-pollution relationship, we employed regression model to confirm and quantify the influences of scale effect and composition effect.

As summerized in Section 1, the increment of industrial pollution can be caused by pure Smith's economic growth even without technological and compositional changes. This is due to the fact that with GDP rising, demands for energy and trading transportation also rise, which degrades environmental quality. Such economic growth therefore exerts a negative scale effect on environment. However economic development of upgrading industrial structures has a positive impact on environment through composition effect. That is to say, as GDP increases, structure of the economy tends to change and the industries tend to conduct cleaner activities that produce less pollution. Therefore, taking into account the unobserved city effect, we further introduced proportions of secondary and tertiary industrial GDP into the revised standard EKC regression model and have (Standard EKC regression model can be seen in Stern (2004)):

$$\ln(\mathrm{var})_{it} = \beta_0 + \beta_1 \ln\mathrm{GDP}_{it} + \beta_2 (\ln\mathrm{GDP}_{it})\text{ }^\wedge 2 + D_3 \mathrm{second}_{it} + \beta_4 \mathrm{third}_{it} + a_i + \varepsilon_{it} \quad (2)$$

which is conducted through first-order differential regression to handle heteroscedasticity.

Table 4 gives the results of the regression. The model has a relatively strong explanatory power (R-squared = 0.5403), and almost all key covariates are significant at the 1% level. Due to scale effect, as total GDP increases by 1%, industrial pollution rises by 6%, which matches the findings in Section 3. GDP in quadratic form is not a significant contributor to industrial pollution, which may imply that GDP has not reached the turning point. Another interesting fact is that the proportion of secondary industry, too, is significant at the 1% level and so it has a positive impact on industrial pollution. There are two possible reasons. One is that such fact is highly correlated with the management of innovative, environmental-friendly and smart secondary industry, and the enterprises transformation from energy-intensive to knowledge-intensive and technology-intensive. The other reason is that cities, under free trade, can conduct focus strategies (Grossman & Kruegar, 1991), which are likely to be environmentally-friendly and meet the demands of citizens for cleaner economy.

Table 4 First-order differential regression

Variable	Coef.	Std. Err.	T	P>|t|
ln (GDP)	.617 9702	.151 2255	4.09	0.000***
$\ln^2$ (GDP)	-.272 9412	.203 8278	-1.34	0.191
Second	-.067 4364	.013 986	-4.82	0.000***
Third	-.062 9209	.014 802	-4.25	0.000***
Intercept	-.094 4409	.041 1585	-2.29	0.029**
R-squared	0.5403			
Observations	34			

Source: China City Statistical Yearbook 2004–2012
Note: *** p<0.001 **p<0.01 *p<0.05

From the findings above, we can conclude that there are ways to improve environmental conditions, which are, changes of structure of the economy, lowering the negative effect on environment through scale effect and improvement in the production process of secondary industry. Typical actions are involvements of better environmental technologies, and improvement of qualities of environmental policies. This is the second conclusion.

The income-pollution relationship after extractions of scale and composition effect out of industrial pollution index is similar to that in **Fig. 3**, so we do not report it again. Based on such observations, we can arrive at the conclusions that there is unique city (cluster) effect beyond scale effect and composition effect and that there is no unified income-pollution relationship in China.

CONCLUSIONS

The production and changes of urban industrial pollution are always accompanied with economic growth, and the unique patterns of economic growth across cities always affect pollution both in quantity and in its changing pattern. This paper investigates the income-pollution relationship of 111 prefectural-level cities in China in year 2004–2012. We find out that (1) scale effect and composition effect and (2) unobserved city effect result in the diversified relationship across cities and the unique patterns that certain cities and clusters hold. And cities with high GDP can take action on the reduction of pollution to be able to have better developing patterns like that in the first cluster – pollution monotonically negatively related to GDP per capita.

Of all five clusters, the first cluster has the ideal developing patterns for future economic growth and thus has few policy implications. First, work on reducing pollution caused by the scale effect, increasing the proportion of environmental-friendly tertiary industrial GDP and keeping the positive effect of secondary industrial GDP on environment. Second, apply green technologies into industrial production and encourage enterprises to conduct research and development in new technologies (Jaffe *et al.*, 2005).

Such actions can be seen in cities of the first clusters. Out of all China ecological demonstrative regions, the amount of cities in the first clusters takes up 52.9%. The technologies applied in these regions were designed for circular and ecological economy, and were carried out with the help of sustainable resources such as information technology and renewable energy. Third, conduct effective government policies in areas of sustainable allocation and consumption of natural resource, which can provide incentives for environmental innovation in a longer period and promote development of environmental industries (Mossalanejad, 2011). Beijing and Shanghai has already made positive efforts to assist the development of high-tech and energy-efficient enterprises such as pollution regulation for high-polluting enterprises and incentive policies.

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