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Abstract

The Environmental Kuznets Curve (EKC) hypothesis proposes that there is an inverse-U-shape relationship between environmental degradation and per capita income. This evidence has been manifested to be existed in most air pollutants and several water pollutants by estimating on cross-country data. Different from most earlier empirical studies, this paper uses the cross-province panel data of seven pollutants from China to investigate whether the EKC hypothesis may even exist on a country level. The estimated results find out that the EKC hypothesis exists in five of these pollutants, while the other two show a N-shape relationship between pollutant emission and per capita income. Moreover, this paper suggests some problems of this regression as being remained for future study.

Keywords: Environmental Kuznets Curve (EKC), pollution emission, economic growth, GDP per capita

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1. Introduction

Fully understanding the impact of economic development on the environmental quality is becoming increasingly important as general environmental concerns are making their ways into main public policy agenda. A number of recent studies have explored the relationship between economic development and environmental quality both on theoretical and empirical level. Theoretical analysis by John and Pecchenino [1], Seldon and Song [19], Stocky [13], and Andreoni and Levinson [12] have derived each transition path for pollution, abatement effort and development under alternative assumptions about social welfare functions, pollution damage, the cost of abatement, and the productivity of capital. Empirical studies (Shafik and Bandyopadhyay [17], Seldon and Song [20], Grossman and Krueger [10], and Holtz-Eakin and Selden [8]) have searched for systematic relationships by regressing cross-country measures of ambient air and water quality on various polynomial specifications of income per capita. There is evidence that the level of environmental degradation measured by many forms of pollution and per capita income follow an inverse-U-shaped pattern, first rising and then falling as income increases. Due to its similarity to the time series of income inequality described by Kuznets [18], the environmental pattern has been labeled the Environmental Kuznets Curve (Selden and Song [20]).

Most of the empirical studies focus on using the cross-country panel data to estimate the relationship between per capita income and various environmental indicators. There are just a few literatures based on individual countries. However, moving from cross-country to a single-country study is a new try for EKC researches, since the study of a single country eliminates the problems associated with data comparison from different countries (Carson *et al* [4]) and more could be learned from an examination of the experiences of individual countries (de Bruyn and Heitz [7]). Moreover, there is no any empirical study that has tested the EKC hypothesis by using data from China. Thus, the main contribution of this paper is that it employs Chinese cross-province panel data and a common methodology to investigate the relationship between the scale of economic activity and environmental quality for a comparative broad set of environmental indicators. The second contribution of this paper is that it includes share of the secondary industry in the regression to investigate the industrial structural effect on environmental quality empirically, which has been seldom done in earlier empirical studies.

The remainder of this paper is organized as follows. The next section introduces the model specification and data description. Section 3 describes the methodological issues and empirical results, and Section 4 draws the conclusion and some suggestions for future study.

2. Model specification and data

2.1 Model specification

Earlier empirical analyses used various specifications to estimate the relationship between pollution and income level. This paper presents the model as below[1]:

(1) $\ln p_{it} = \beta_{0i} + \beta_1 \ln y_{it} + \beta_2 (\ln y_{it})^2 + \beta_3 (\ln y_{it})^3 + \beta_4 ind_{it} + \beta_5 \ln pd \ + \beta_6 trend + \varepsilon_{it}$

where p : per capita pollutant emission

y : per capita GDP

ind : share of the secondary industry

pd : population density

$trend$: time trend

i : a province(metropolitan city) index

t : a time index

ε : an error term.

Table 1 lists the conditions for different relationships between pollution emissions and per capita income, presented by different estimated coefficient signs of per capita GDP and its quadratic and cubic terms. We notice that emissions can be said to exhibit a meaningful Kuznets relationship with per capita GDP if $\beta_1 > 0, \beta_2 < 0$ —and if the turning point $-\beta_1 / 2\beta_2$ is a "reasonably" low number (Seldon and Song [20])[2].

As for the other explanatory variables in addition to per capita GDP, we include shares of the secondary industry, population density and time trend into the models to improve the estimation. The sign for share of the secondary industry is expected to be positive, which shows the positive relationship between pollutant emission and secondary industry. Meanwhile, population density is expected to enter in equation (1) with a positive sign, since aggregate emission ought to increase with population growth. The estimated coefficient for time trend means the average growth rate of estimated pollutant emissions, which to some extent reflects the efectiveness of current Chinese environmental policy.

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[1] In the cases of Arsenic, Cadmium, Mercury and Industrial waste stock, we use $\ln(p_{it} + 0.000000001)$ as the dependent variable since the samples of these pollutants include zero.

[2] Since we include cubic terms of per capita GDP in the regression, therefore, β_3 must be zero for the EKC's existence.

Table 1

Coefficient signs of per capita GDP and its quadratic and cubic terms

Coefficient signs	Relationship between pollution and income
$\beta_1 > 0, \beta_2 < 0, \beta_3 = 0$	Inverse-U-shaped curve (EKC)
$\beta_1 < 0, \beta_2 > 0, \beta_3 = 0$	U-shaped curve
$\beta_1 > 0, \beta_2 < 0, \beta_3 > 0$	N-shaped curve
$\beta_1 < 0, \beta_2 > 0, \beta_3 < 0$	Inverse-N-shaped curve

An issue concerns that besides the explanatory variables presented in the estimation model, there are also some other exogenous factors that affect emissions. For instance, climate and geography vary widely among provinces in China and may well be correlated with emissions. Insofar as these factors cause the error terms in model to be correlated among provinces for a given period, OLS estimates that ignore this correlation will be inefficient. Moreover, if these omitted variables are correlated with per capita GDP, then random-effects estimates will also yield biased and inconsistent results. For details of this issue, we will present in the next section.

2.2. Data

Due to the limitation of data, this paper uses the panel data of two air pollutants (SO_2 and Dust Fall) from 1990-2001, four water pollutants (COD: Chemical Oxygen Demand, Arsenic in water, Cadmium in water and Mercury in water) and one solid pollutant (Industrial waste stock) from 1993-2001 in China's 31 provinces and metropolitan cities. Table 2 lists the descriptive statistics of per capita emissions of SO_2, Dust Fall, COD, Arsenic, Cadmium, Mercury and Industrial waste stock, per capita GDP, share of the secondary industry, and population density.

3. Methodological issues and empirical results

3.1 Methodological issues

A first methodological issue concerns the degree of the polynomial. We first use t test to check whether the cubic terms of per capita GDP are statistically different from zero or not. If the cubic terms are found not to be significantly different from zero even at the 10% level, we estimate the equation (1) without the cubic terms. In contrast, if they are found to be significantly different from zero, we present the estimates of equation (1) with cubic terms.

TABLE 2

Descriptive Statistics of Variables

	Sample mean	Sample median	Sample maximum	Sample minimum	Standard deviation	Number of observations
Per capita SO_2 (kg)	14300.47	12530.63	48067.47	279.087	9103.715	372
Per capita Dust Fall(kg)	10618.39	7991.571	42124.54	36.036	8061.554	372
Per capita COD (kg)	5.566978	5.024658	31.52133	0.246667	3.838718	279
Per capita Cadmium (kg)	0.000117	1.34E-05	0.00164	0	2.36E-05	279
Per capita Arsenic (kg)	0.001291	0.000182	0.031921	0	0.004116	279
Per capita Mercury (kg)	1.09E-05	2.28E-06	0.00016	0	2.28E-05	279
Per capita Industrial Waste Stock (kg)	5314.438	3637.265	39689.99	0	6096.802	279
Population density (person/km^2)	342.8924	244.6974	2640.17	1.80723	412.9402	372
The secondary industry share (%)	46.1828	46.25	81.00	9.00	10.6263	372
Per capita GDP (yuan)	5213.78	4091.00	37382.00	778.00	4966.51	372

[a]Data source: Chinese Statistical Yearbook (1990-2001)

[b]Numbers of observation of per capita GDP, population density and the secondary industry share are 279 in COD, Arsenic, Cadmium, Mercury and Industrial waste stock cases.

The second issue is that we employ F test to check the homogeneity of the province effects. If province effects are found to be existed, then estimating equation (1) by OLS which omit the province effects will lead biased and inefficient estimators.

The third issue concerns choosing between fixed-effects model and random-effects model. An important criterion here is whether the province effects are correlated with the explanatory variables. In the absence of such correlation, random-effects estimation is consistent and efficient. In contrast, if such correlation exists, there may be omitted variable bias, necessitating fixed-effects estimation (Selden and Song [20]). The disadvantage of fixed-effects model is that there are too many parameters to be estimated and hence loss of degrees of freedom which can be avoided if we either assume the same intercept for all the cross sectional units, or assume β_{0i} to be random variables. Nevertheless, the random-effects model is not totally free from problems. In case where the province effects are correlated with explanatory variables, the random-effects model is similar to an omitted variable specification which leads to biased parameter estimates, making a fixed-effects model a more appropriate choice. In order to help choose between these two approaches, we employ the Hausman test in this paper.

3.2 Empirical results

Tables 3-4 present estimated results. A first issue concerns the homogeneity of the province effects. In all cases, the null hypothesis of homogeneity is rejected by a wide margin (see F statistics reported in the tables). This suggests that OLS estimators are inefficient at best and may yield biased coefficient estimates.

The Hausman test suggests that in all the cases except Arsenic, random-effects estimation is preferred to be accepted[3].

The most important issue concerns the curvature of the relationship between per capita pollutant emissions and per capita GDP. The results of the estimation indicate that in all the water pollutants and SO_2 cases, the inverse-U-shaped EKC relationships are presented, while in other two pollutants (Dust Fall and Industrial waste stock) cases, a N-shaped curve are presented since that the null hypothesis of which the cubic terms of per capita GDP is not different from zero can not be rejected even at 10% level[4].

Turning to the other explanatory variables issue, in all the cases except SO_2, the estimated signs of share of the secondary industry are consistent with the expected positive one. For the signs of population density, in air pollutants and solid pollutant cases, they show the expected positive one, although two of them are not statistically significant. But for water pollutants, only in COD case, the estimated sign shows the consistency with the expectance, while in other three cases it shows the negative sign.

Comparing the estimated income turning points with per capita GDP data in 2001, we find that SO_2 and Mercury emissions have already been on the decreasing transition path, while Arsenic emission is still on the increasing transition path. In Cadmium and COD cases, there are still 5 and 15 provinces respectively being on the emission increasing transition path. In Dust Fall and Industrial waste stock cases, the emissions

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[3] We only list the estimated results for the accepted models according to Hausman test. The other estimated results are available for request.

[4] The N-shaped curve indicates the deteriorating environmental performance at the initial phases of growth which is followed by a phase of improvement and then a further deterioration once a critical level of income is reached.

TABLE 3

Estimated Results for Water Pollutants

(t statistics in parentheses)

	Arsenic	COD	Cadmium	Mercury
Constant	721.8124*** (4.51)	63.71565* (1.70)	253.5605 (1.37)	475.0844** (2.45)
ln(per capita GDP)	8.441154*** (2.83)	4.601456*** (5.51)	8.188167** (2.01)	5.528574 (1.17)
(ln(per capita GDP))^2	-0.3914011** (-2.20)	-0.2630823*** (-5.40)	-0.4795596** (-2.02)	-0.3723443 (-1.36)
The secondary industry share	0.0767181* (1.89)	0.0211059** (2.29)	0.0807817* (1.76)	0.0718029 (1.59)
ln(population density)	-10.96644*** (-3.29)	0.1634534** (2.28)	-0.1690892 (0.46)	-0.0085571 (-0.03)
Time trend	-0.3606806*** (4.23)	-0.0420511** (-2.20)	-0.1523534* (-1.61)	-0.2562206** (-2.58)
t-test for cubic term	0.79	-1.05	1.36	0.48
Adjusted R^2	0.786	0.770	0.714	0.562
Hausman test	877.45 (5)	5.05 (5)	4.59 (5)	4.34 (5)
Accepted model	Fixed-effects	Random-effects	Random-effects	Random-effects
Turning point (yuan)	48,207	6,298	5,101	(1,691)
Sample size	279	279	279	279

[a]One, two, or three asterisks indicate that a coefficient estimate is significantly different from zero at 10%, 5% or 1% level, respectively.

[b] F statistics for the null hypothesis of homogeneity is 29.29, 20.04, 18.11 and 8.69 for Arsenic, COD Cadmium and Mercury, respectively.

are currently on the decreasing transition path in most provinces[5], however after per capita GDP reaches 24,847 yuan (in Industrial waste stock case) and 69,071 yuan (in Dust Fall case), they will increase again. This result may give Chinese government more incentive to make much more efforts on abating environmental pollution while keeping continuous rapid economic growth.

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[5] Only except for Guizhou province with per capita GDP at 2,895 yuan in 2001 which is still on the emission increasing transition path in Industrial waste stock case.

TABLE 4

Estimated Results for Air and Solid Pollutants

(t statistics in parentheses)

	SO_2	Dust Fall	Industrial waste stock
Constant	10.8022 (0.47)	-102.58** (-2.18)	-222.925** (-2.23)
ln(per capita GDP)	1.225114*** (4.19)	20.04458*** (2.78)	41.97864** (2.07)
$(\ln(\text{per capita GDP}))^2$	-0.084602*** (-4.91)	-2.215366*** (-2.59)	-4.667846** (-1.98)
$(\ln(\text{per capita GDP}))^3$	—	0.0787306** (2.34)	0.1708688* (1.88)
Share of the secondary industry	-0.0063048*** (-2.72)	0.0197386*** (4.16)	0.0484451** (2.36)
ln(population density)	0.3131878*** (3.92)	0.1575465* (1.80)	0.1397132 (0.84)
Time trend	-0.0070271 (-0.59)	0.0221726 (0.99)	0.0519431 (1.30)
t-test for cubic term	-1.21	2.34	1.88
Adjusted R^2	0.939	0.812	0.975
Hausman test	7.09 (5)	10.59 (6)	7.20 (6)
Accepted model	Random-effects	Random-effects	Random-effects
Turning point (yuan)	1,395	2,031 69,072	3,268 24,847
Sample size	372	372	279

[a]One, two, or three asterisks indicate that a coefficient estimate is significantly different from zero at 10%, 5% or 1% level, respectively.

[b] F statistics for the null hypothesis of homogeneity is 124.82, 30.39 and 24.84 for SO_2, Dust Fall and Industrial waste stock, respectively.

In most pollutants estimated in this paper, the income turning points estimated by using cross-country panel data in earlier empirical studies were much higher than the results presented in this paper. We think the reasons may probably be existed in three ways. First, largely using of efficient anti-pollution machinery in recent years in China shifts the turning points of EKC towards the origin. Second, the subsidies from developed countries help China spend much on pollution abatement, which also makes the EKC lower and flatter and thus decreases the turning points. Third, the data used in this paper is from 1990-2001 (for water and solid pollutants, from 1993-2001), maybe it is too short for the estimation of long-run effects. Therefore, although the estimated turning points for these pollutants in this paper are comparatively lower and several pollutants have already been on the decreasing transition path, there still remains one point to be noticed, that is the absolute aggregate emission level of China is much higher than the international average level, which indicates that the low turning points do not mean Chinese government can stop investing on pollutant abatements. In contrast, if the abatements are abandoned, the curve may be changed to another shape which results in the continuing increase or re-increase of these pollutants.

Finally, we notice that these five pollutants that have shown inverse-U-shaped curve should not be viewed as representative of all pollutants in China. In fact, it seems likely that the combination of important own-province pollution effects and relatively low abatement costs makes these pollutants to exhibit inverse-U-shape relationships with income. Thus, we can only say that in these five pollutants, the EKC hypothesis is found to be existed in China. It is likely that some other pollutants, such as CO_2, which are costly to be abated, may appear to rise monotonically with income[6].

4. Conclusion

This paper uses the cross-province panel data for seven pollutants from China to investigate the relationship between economic growth and environmental quality in China. The estimated results indicate that there exists an Environmental Kuznets Curve in five pollutants. The other two pollutants show an N-shaped curve. Meanwhile, a positive effect caused by share of the secondary industry on emissions has been empirically found in most pollutants.

Finally, in most empirical EKC literatures including this paper, EKC are always estimated in the form of a single equation. However, as we know, pollution emission may reduce production through the restriction of environmental input's supply via environmental degradation or the loss of workdays due to health problem caused by pollution, therefore influence the level of per capita income. Thus, generally, the economy and its environment are jointly determined (Perrings, [14]) and estimating single equation relationships by ordinary least squares where simultaneity is existed

[6] Holtz-Eakin and Selden [8] used cross-country panel data and found the CO_2 emission appears to have a monotonic EKC.

produces biased and inconsistent estimates (Stern, [5]). From this view, it may be therefore more appropriate to use a simultaneous-equation model for regression[7].

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