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CO_2 emissions and economic growth nexus in China: A cointegration analysis of the four-stage environmental Kuznets Curve

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This research puts forward four-stage EKC hypothesis based on the traditional EKC theory (two stages), and also checks the hypothesis by investigating the relationships among CO_2 emissions, energy consumption and economic growth with a cubic model in logarithm form based on the panel data for 29 provinces in China over the period 1995–2010. The empirical tests find some evidences for the existence of the four-stage EKC for CO_2 emissions in China. The long-run cointegrated relationships among the three variables have been found in our empirical results. The regression results find a maxima turning point of the four-stage EKC between economic growth and CO_2 emissions. The causality results show that there exist two bidirectional causalities between energy consumption and CO_2 emissions, and also between economic growth and energy consumption. Moreover, there is a Granger causality running from CO_2 emissions to economic growth. Some policy implications of the theoretical and empirical analysis results are proposed at last.

Key words: CO_2 emissions; economic growth; energy consumption

INTRODUCTION

The increasing threat of global warming has called for more and more discussions all over the world. The major greenhouse gas (GHG) is CO_2 emissions which are considered to be the main gas leading to global warming [1]. But CO_2 emissions have the nature of the "tragedy of the commons" and damage indirectly, so countries may be not interested in reducing CO_2 emissions during its rapid economic development period. So, CO_2 emissions problem has increasingly become the focus of academic research.

The relationship between economic growth and environmental pollution is described usually by the hypothesis of Environmental Kuznets Curve (EKC) in which, environmental pollution increases with economic growth first, and then decreases when the per capita income reaches a certain critical level [2]. Ever since, the EKC hypothesis has become an important research issue which has led to a large number of theoretical and empirical literature. There is also vigorous discussion on the applicability of EKC for CO_2 emissions [3; 4; 5; 6; 7; 8; and so on).

Some researchers claimed the EKC for CO_2 emissions was non-existent. Selden and Song performed a study on the EKC in both RE and FE models, and found no turning point for CO_2 emissions [9]. Gangadharan and Valenzuela adopted data from the World Development Indicators (WDI) 1998 and found an upward straight line for CO_2 emissions [10]. Lindmark performed a study on the EKC for CO_2 emissions just in Sweden, using dynamic structural model [11]. And he didn't find any turning point for CO_2 emissions and no evidences for inverted U-shape EKC. Richmond and Kaufman tested the EKC for CO_2 emissions and energy use with a panel data of 36 countries [12]. For OECD nations, there is limited support for a turning point in the relationship between income and CO_2 emissions. For non-OECD nations, there is no turning point in the relationship between income and CO_2 emissions. Miah et al studied the EKC for greenhouse gases (GHG) including CO_2, SO_x and NO_x which showed that EKC for CO_2 emissions was following a monotonous straight line in most cases [13]. Ajmi et al. tested EKC for CO_2 emissions in the G7 countries, the finding of inverted N-shaped curves in Italy and Japan lends no support to the traditional EKC hypothesis [14]. Kang et al. tested EKC for CO_2 emissions in China using a spatial panel data model, and found that the relationship between economic growth and CO_2 emissions shapes as an inverted-N trajectory [15]. Dogan and Turkekul tested EKC for CO_2 emissions, and did not support the validity of the environmental Kuznets curve (EKC) hypothesis for the USA because real output leads to environmental improvements while GDP^2 increases the levels of gas emissions [16].

Other researchers considered the EKC for CO_2 emissions was existent. Holtz-Eakin and Selden tested the EKC for CO_2 emissions [3]. They used a quadratic model for data estimation, and obtained some support of EKC for CO_2 emissions. However, their estimated turning point occurs at a very high

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level of per capita income ($35,428 in per capita 1986 price). Agras and Chapman examined data from 34 countries including developed and developing country, and found a turning point of per capita GDP for CO_2 emissions at $13,630 [17]. Maradan and Vassiliev examined a number of countries, and they found a turning point of per capita GDP for CO_2 emissions at $5,924 [18]. Their minimum per capita GDP for turning point was $325 and maximum was $17,508 in 1985 price (expressed in PPP). Saboori et al. studied the EKC for CO_2 emissions in Malaysia, and they found the turning point of per capita real income for CO_2 emissions was $4700 [7]. Apergis found that the EKC hypothesis holds in 12 out of the 15 countries [8]. Bilgilia et al. studied the EKC for CO_2 emissions with a panel data of 17 OECD countries, the findings supported the EKC hypothesis, and they found the turning point was from $10400 to $88890, so they believed EKC hypothesis was independent of income level [19].

Some recent studies added other potential determinants of CO_2 emissions such as energy consumption by Ang [20], Menyah and Wolde-Rufael [21], Ajmi et al. [14]; foreign trade by Halicioglu [22], Nasir and Rehman [23]; urbanization by Zhang and Cheng [24], Iwata et al. [6] and Hossain [25]; employment by Sari and Soytas [26], Ghosh [27]; population, industry energy intensity and share of nonfossil fuels in primary energy by Liddle [28]; trade openness and financial development by Dogan and Seker [29]; trade openness, energy structure, urbanization and population density by Kang et al. [15]. But still, their conclusions cannot be unified.

The affirmative results of EKC show that there is a turning point of per capita GDP for CO_2 emissions, but the turning point is not unified. Some negative studies show there is no evidence of inverted U-shape EKC for CO_2 emissions, and some other authors even found upward straight line for many countries. It is of course a warning for developing countries that waiting for the CO_2 emissions reduction automatically is dangerous.

Our study extends EKC hypothesis and provides a new empirical analysis on the EKC for CO_2 emissions in China.

FOUR-STAGE EKC

We analyze in the circumstances of an open economy, and assume that the economy can always maintain growth. We propose another possible form of EKC theory that may exist in four-stage EKC.

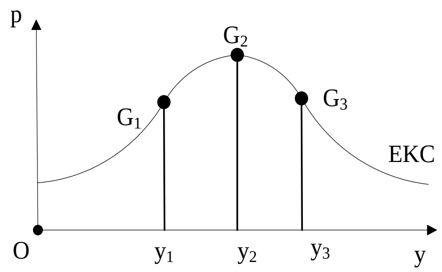

Fig. 1. Four-stage EKC curve

Subject to space, we simplified the analysis. The process can be reflected in figure 1, the curve slope is negative. The per capita environmental pollution increases with per capita output, and the growth rate is changing gradually from incr easing to decreasing at the inflection point G1 wher e convex function converts to concave function.
Define y is per capita output, p is per capita environmental pollution. Then the left of G_1 is $\partial y/\partial p>0$, $\partial^2 y/\partial p^2>0$; on the right of G_1 is $\partial y/\partial p>0$, $\partial^2 y/\partial p^2<0$ .The left of G_3 is $\partial y/\partial p<0$, $\partial^2 y/\partial p^2<0$; on the right of G_1 is $\partial y/\partial p<0$, $\partial^2 y/\partial p^2>0$.

DATA AND MODEL

Based on the four-stage EKC hypothesis we can build a per capita quadratic equation model as follows:

$$\ln(c_{it})=\alpha_{it}+\beta_{1i}\ln(E_{it})+\beta_{2i}\ln(y_{it})+\beta_{3i}\ln(y_{it}{}^2)+\varepsilon_{it} \quad (1)$$

Where *c* is per capita CO_2 emissions; *y* is per capita GDP; *E* is per capita energy consumption; *i* denotes the provinces in China; *t* denotes the time period; ε is the standard error term. But based on our research in section 2, the model may not be a quadratic function. As the study in Grossman and Krueger [2], cubic curve may also occur. So we can build the estimation model as follows:

$$\ln(c_{it})=\alpha_{it}+\beta_{1i}\ln(E_{it})+\beta_{2i}\ln(y_{it})+\beta_{3i}\ln(y_{it}{}^2)+\beta_{4i}(y_{it}{}^3)+\varepsilon_{it} \quad (2)$$

This study uses annual panel data from 1995 to 2014 in 29 provinces. The province of Tibet is excluded in the empirical analysis because of the lack of data. And the data for Chongqing municipality is merged into Sichuan province for maintaining the consistency throughout the whole study period. The data of energy consumption and GDP for each province comes from “China Energy Statistical Yearbook” (EDNBSC, various years) and “China Statistical Yearbook” (NBSC, various years). China's provinces did not release the CO2 emissions data, but release the fossil energy consumption breakdown by each fuel category, and the data also comes from "China Energy Statistical Yearbook" (EDNBSC, various years). According to the chapter sixth volume two in national greenhouse gas inventory guide formulated by the IPCC (2006) which provides the reference method, total CO_2 emissions can be estimated according to all kinds of fossil energy consumption. On this basis, Chen estimated the CO2 emission coefficient of coal, crude oil and natural gas and so on. This paper will draw on this CO_2 emission coefficient [30]. Per capita CO_2 emissions and per capita energy consumption are measured in metric tons, and real per capita GDP is measured in constant 1985 Chinese Yuan. Table 1 above shows the summary statistics of the three variables (in nature logarithm) for the selected years.

Table 1. Summary statistics of 29 provinces for selected years in China

Variable	Statistics	1995	1999	2003	2006	2010	2014
c (Ton)	Mean	1.048	1.081	1.378	1.746	2.007	2.136
	S.D.	0.526	0.514	0.464	0.445	0.408	0.416
E (Ton)	Mean	0.132	0.165	0.463	0.830	1.092	1.220
	S.D.	0.513	0.511	0.487	0.473	0.456	0.440
y (Yuan)	Mean	7.545	7.889	8.238	8.587	9.030	9.391
	S.D.	0.538	0.563	0.548	0.542	0.502	0.136

And then we make the curve between per capita CO_2 emissions and real per capita GDP as Fig. 2.

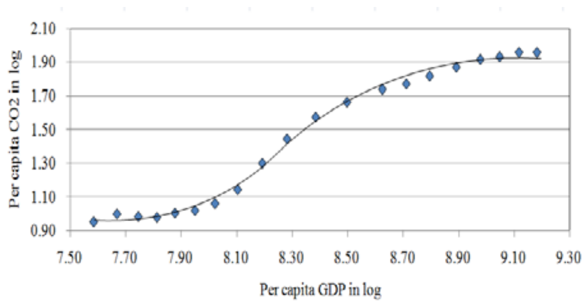

Fig 2. Long-run EKC relationship

The graphical representation of the relationship between per capita CO_2 emissions and real per capita GDP in log levels in Fig. 2 does not accord with an inverted-U shape of EKC like other studies. The curve may have an inflection point (cut-off point of the concave curve and convex curve) except the extremum, just like the left part of figure 1. So model 3 may pass the testing. Under the analyses above, it is expected that $\beta_2<0$, $\beta_3>0$ and $\beta_4<0$. And It is expected that $\beta_1>0$ as an increase in energy consumption will probably cause an increase in CO_2 emissions.

ESTIMATION METHODOLOGY AND RESULTS

Panel unit root tests

The null hypothesis of the unit root tests is that there exists unit root (i.e. the variables are non-stationary), and the alternative hypothesis is that no unit root exists in the series (i.e. the variables are stationary). Table 2 shows the results of the panel unit root tests for variables.

Table 2. Results of IPS panel unit root tests 1995-2014

Variables	Level	First-order differential
$\ln(c)$	1.8275(0.9662)	-4.3426(0.0000)***
$\ln(E)$	1.8560(0.9765)	-4.6563(0.0000)***
$\ln(y)$	2.0902(0.9830)	-3.5462(0.0002)***
$\ln(y^2)$	2.0901(0.9829)	-3.5462(0.0002)***
$\ln(y^3)$	2.0901(0.9829)	-3.5461(0.0002)***

Notes: All panel unit root tests were performed with restricted intercept and trend for all variables. * Represent significance at 10%. ** Represent significance at 5%. *** Represent significance at 1%.

It can be seen from Table 2 that the variables $\ln(c)$, $\ln(E)$, $\ln(y)$, $\ln(y^2)$ and $\ln(y^3)$ are statistically insignificant in level form due to the IPS test. However, all the variables with first-order differential form become stationary. Therefore, we may conclude that each variable is integrated of order one.

Panel cointegration tests

Since all the variables with first-order differential form are stationary, so we can do the panel cointegration tests. If panel and group statistics reject the null hypothesis, then there exist cointegration relationships among variables. Table 3 shows the results of panel cointegration test.

Table 3. Results of panel cointegration tests 1995-2014

Panel (within dimension)		Group (between dimension)	
Statistics	Value(Prob)	Statistics	Value(Prob)
Panel v-Statistic	4.569 (0.000)***	Group rho-Statistic	0.309 (0.621)
Panel rho-Statistic	-2.573 (0.005) ***	Group PP-Statistic	-4.510 (0.000)***
Panel PP-Statistic	-3.660 (0.000) ***	Group PDF-Statistic	-6.174 (0.000)***
Panel ADF-Statistic	-4.521 (0.000) ***	–	–

It can be seen from Table 3 that there are four panel statistics reject the null hypothesis, two groups of statistics reject the null hypothesis, and one group statistics admits it. Considering the rho-statistics has lower power than the PP-statistics, and all other statistics support the existence of cointegration relationship, so it may be reasonable to accept the existence of cointegration relationship.

Then we can obtain the following long-run cointegrating equation by estimating Eq. (2):

$$\ln(c)=13.67+1.14\ln(E)-6.19\ln(y)+0.83\ln(y^2)-0.03\ln(y3) \quad (3)$$

$$(11.73)^{***} \ (7.45)^{***} \ (-2.77)^{***} \ (2.18)^{**} \ (-3.21)^{***}$$

Using fixed effects model we get estimation results above. The system estimated $AR^2=0.966$, and F=875. Due to Eq. (3), we find that the sign of the coefficients are just as the expected: ln(*E*) has a positive promotion to ln(*c*); ln(*c*) is negatively related to ln(*y*), positively related to $\ln(y^2)$, and negatively related to $\ln(y^3)$.

Let $\partial \ln(c)/\partial \ln(y)=0$, we get ln(*y*)=5.4860 and ln(*y*)= 10.6334 approximately. So we get a very low minimum value about 241 Chinese Yuan in 1985 price (in our analysis after section 1, all the price is in year 1985), and get a maximum value about 41500 Chinese Yuan which has not yet occurred. Let $\partial^2 \ln(c)/\partial \ln(y)^2=0$, we get ln(*y*)= 8.2587. If $\ln(y)>8.2587$, $\partial^2 \ln(c)/\partial \ln(y)^2<0$, and if $\ln(y)<8.2587$, $\partial^2 \ln(c)/\partial \ln(y)^2>0$. So we get an inflection point (cut-off point of the concave and convex curve). Value of ln(*y*) = 8.2587, means inflection point is about 3861 Chinese Yuan which has happened in all provinces. So the growth rate of CO_2 emissions may be declined after that. The trend of factor price equalization seems to appear in China already, especially the labor price. So the estimations may fit for China's facts. Now, China has got through the first stage of four-stage EKC, and is in the second stage of four-stage EKC. We do not get a traditional inverted U-shaped curve, but the results provide some evidences for the four-stage curve presented in fig 1.

Granger causality tests

The panel cointegration test results in table 3 suggest that cointegrating relationships exist among CO_2 emissions, energy consumption and economic growth. So it is reasonable to test the Granger causality relationships among the variables. The dynamic error correction model can be expressed as follows:

$$\begin{aligned}\Delta\ln(c_{it}) &= a_{1j}+\sum_{k=1}^{q}\delta_{1ik}\Delta\ln(c_{it-k})+\sum_{k=1}^{q}\varepsilon_{1ik}\Delta\ln(E_{it-k}) \\ &+\sum_{k=1}^{q}\phi_{1ik}\Delta\ln(y_{it-k})+\sum_{k=1}^{q}\varphi_{1ik}\Delta\ln(y^2{}_{it-k})+ \\ &\sum_{k=1}^{q}\gamma_{1ik}\Delta\ln(y^3{}_{it-k})+\alpha_{1i}ECM_{it-1}+e_{1it}\end{aligned} \quad (4)$$

$$\begin{aligned}\Delta\ln(E_{it}) &= a_{2j}+\sum_{k=1}^{q}\delta_{2ik}\Delta\ln(c_{it-k})+\sum_{k=1}^{q}\varepsilon_{2ik}\Delta\ln(E_{it-k}) \\ &+\sum_{k=1}^{q}\phi_{2ik}\Delta\ln(y_{it-k})+\sum_{k=1}^{q}\varphi_{2ik}\Delta\ln(y^2{}_{it-k}) \\ &+\sum_{k=1}^{q}\gamma_{2ik}\Delta\ln(y^3{}_{it-k})+\alpha_{2i}ECM_{it-1}+e_{2it}\end{aligned} \quad (5)$$

$$\begin{aligned}\Delta\ln(y_{it}) &= a_{3j}+\sum_{k=1}^{q}\delta_{3ik}\Delta\ln(c_{it-k})+\sum_{k=1}^{q}\varepsilon_{3ik}\Delta\ln(E_{it-k}) \\ &+\sum_{k=1}^{q}\phi_{3ik}\Delta\ln(y_{it-k})+\sum_{k=1}^{q}\varphi_{3ik}\Delta\ln(y^2{}_{it-k}) \\ &+\sum_{k=1}^{q}\gamma_{3ik}\Delta\ln(y^3{}_{it-k})+\alpha_{3i}ECM_{it-1}+e_{3it}\end{aligned} \quad (6)$$

$$\begin{aligned}\Delta\ln(y^2{}_{it}) &= a_{4j}+\sum_{k=1}^{q}\delta_{4ik}\Delta\ln(c_{it-k})+\sum_{k=1}^{q}\varepsilon_{4ik}\Delta\ln(E_{it-k}) \\ &+\sum_{k=1}^{q}\phi_{4ik}\Delta\ln(y_{it-k})+\sum_{k=1}^{q}\varphi_{4ik}\Delta\ln(y^2{}_{it-k}) \\ &+\sum_{k=1}^{q}\gamma_{4ik}\Delta\ln(y^3{}_{it-k})+\alpha_{4i}ECM_{it-1}+e_{4it}\end{aligned} \quad (7)$$

$$\begin{aligned}\Delta\ln(y^3{}_{it}) &= a_{5j}+\sum_{k=1}^{q}\delta_{5ik}\Delta\ln(c_{it-k})+\sum_{k=1}^{q}\varepsilon_{5ik}\Delta\ln(E_{it-k}) \\ &+\sum_{k=1}^{q}\phi_{5ik}\Delta\ln(y_{it-k})+\sum_{k=1}^{q}\varphi_{5ik}\Delta\ln(y^2{}_{it-k}) \\ &+\sum_{k=1}^{q}\gamma_{5ik}\Delta\ln(y^3{}_{it-k})+\alpha_{5i}ECM_{it-1}+e_{5it}\end{aligned} \quad (8)$$

Where *q* is the lag length for the differenced variables, and it can be obtained by the Engle–Granger approach. The dynamic error correction modles in Eqs. (4)–(8) can be derived from the long-run equilibrium Eq. (9) as follows:

$$E\hat{C}M_{it}=\ln(c_{it})-\hat{\alpha}_{it}-\hat{\beta}_{1i}\ln(E_{it})-\hat{\beta}_{2i}\ln(y_{it})-\hat{\beta}_{3i}\ln(y_{it}{}^2)-\hat{\beta}_{4i}\ln(y_{it}{}^3) \quad (9)$$

Table 4. Results of panel Granger causality tests 1995-2014

Dependent Variables	Independent Coefficient			
	$\Delta\ln(c)$	$\Delta\ln(E)$	$\Delta\ln(y)\,\Delta\ln(y^2)\,\Delta\ln(y^3)$	EMC
$\Delta\ln(c)$	-	9.6201^{***}	15.4563^{***}	32.7993^{***}
$\Delta\ln(E)$	9.5632^{***}	-	13.7422^{***}	17.7645^{***}
$\Delta\ln(y)\,\Delta\ln(y^2)\,\Delta\ln(y^3)$	1.2025	8.8364^{***}	-	1.5122

Table 4 summarizes the results of panel short-run and long-run Granger causality tests. In the short run, there is bidirectional causality between CO_2 emissions and energy consumption in China. It indicates that an increase in energy consumption will lead to an increase in CO_2 emissions and an increase in CO_2 emissions also means more energy use. One reason is that fossil energy accounts for a large proportion in total energy consumption. There is also bidirectional causality between energy consumption and economic growth. It means that energy plays an important role in forcing economic growth, and Chinese economic development also means more energy use. Furthermore, it can be found that there is a Granger causality running from CO_2 emissions to economic growth. So it's to say CO_2 emissions are the cost to promote Chinese economic development.

In the long-run tests, there exist bidirectional causality between energy consumption and CO_2 emissions as shown in Table 4. However, economic growth doesn't respond to deviations from long-run equilibrium.

CONCLUSION

Our research put forward the four- stage EKC hypothesis based on but expands the application of the traditional EKC theory. Chinese data of CO_2 emissions and economic growth provided some evidences for the existence of the four- stage EKC. The four-stage EKC has three turning point. So we believe that CO_2 reduction along with economic growth after a turning point is not certain, it depends on which stage the country is in.

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