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Are there Environmental Kuznets Curves for China Province-level CO_2 emissions

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Abstract. For the sake of finding out which provinces in China can achieve low-carbon development as early as possible, this paper verifies whether the relationship between economic growth and its environmental degradation meet the Environmental Kuznets Curves (EKC) hypothesis in China. The relationship is reflected by per capita GDP and per capita carbon dioxide (CO_2) emissions during 1995-2015. The existence of China's inverted U-shaped curve is determined. Besides, the empirical analysis of the EKC is also carried on each of the 30 provinces. It is found that the EKC of economic growth exists in 18 provinces, of which 9 provinces exceed their respective turning points of per capita GDP in 2015.

1. Introduction

Global warming is the main feature of climate change, and a series of disasters triggered by climate change has been a global concern. Based on BP statistics for 2016 [1], China's CO2 emissions account for 27.3% of the global CO2 emissions, and China remains the world's largest CO2 emitter. The development pattern of high energy consumption and high CO2 emissions has worsened the atmosphere, furthermore, and seriously endangered people's health, making China become one of the injured countries. Therefore, it forces China to achieve a low-carbon development. What kind of provinces should currently support the realization of low-carbon development first? Are there EKC for China province-level CO2 emissions?

There have been many kinds of literature on the EKC verification in China in recent years. The EKC running from the regional industrial CO2 emissions efficiency and regional income was verified, and there was an N-shaped relationship [2]. Using the time series regression to test the EKC hypothesis of CO2 emissions and economic growth, that is, GDP, from 1977 to 2013 [3], and regression results showed that the EKC existed. The data of Chinese industrial CO2 emissions at the provincial panel in 2000-2013 accepted the existence of the EKC hypothesis [4]. Another study [5] experienced a return on per capita CO2 emissions and per capita income for the provincial panel data of China in 1995-2011 and concluded that there was an N-shaped curve rather than a classic inverted U-shaped curve.

Although there have been many printed papers studying on Chinese EKC, articles on whether per capita GDP has exceeded its threshold in China are still limited. This paper studies the thresholds of the EKCs for economic growth reflected by per capita GDP, and attempts to determine the potential of Chinese provinces' low-carbon development.

2. Data and Methodology

2.1. Data.

The fossil fuels in this study include 1-coal, 2-gasoline, 3-kerosene, 4-diesel, 5-fuel oil and 6-gas, whose data comes from 'China energy statistics yearbook' with the time span of 2002-2015 [6]. The data of CCF_i is from [7], that of HE_i and COF_i is from [8]. The specific formula of CO2 emissions is as follows:

$$CO_2 emissions = \sum_{i=1}^{6}\left(F_i \times CCF_i \times HE_i \times COF_i \times \frac{44}{12} \right), \quad (1)$$

Where i=1, 2, 6, F_i represents the amount of i-fossil fuel (104 tons), CCF_i represents the carbon content factor (tons carbon/trillion Joules), HE_i represents the thermal equivalence (trillion Joules/104 tons), and COF_i represents the carbon oxidation factor (%).

Thirty provinces in China are studied as the data of the other four provinces (Hong Kong, Macao, Xizang and Taiwan) are unavailable. Although Chinese provinces' GDP can be traced back to earlier historical data, their population and consumption of fossil fuels cannot be tracked before 1995. Therefore, the data from 1995 to 2015 are selected to analyze the relationship between GDP and CO2 emissions. As the city of Chongqing was separated from Sichuan province in 1996, the economic data of Chongqing and Sichuan were together in 1995. For a unified calculation, the two individuals obtain their data in 1995 in accordance with the ratio of their economy in 1996. The price index, population and GDP of each province in each year are all from National Bureau of Statistics of the People's Republic of China and are available on http://www.stats.gov.cn/tjsj/.

2.2. Models and methods

The model draws lessons from the early EKC hypothesis model of predecessors [9]. Eq. (2) reflects the relationship between environmental degradation represented by per capita CO2 emissions and economic growth stood by per capita GDP as follows

$$\ln C_{it} = \alpha_i + \beta_1 \ln G_{it} + \beta_2 \left(\ln G_{it}\right)^2 + \beta_3 Ln\left(\sum_{j=1}^{n} w_{ij} C_{jt}\right) + \beta_4 LnA_{it} + \beta_5 E_{it} + \varepsilon_{it}, \quad (2)$$

where C_{it} is the i provincial per capita CO2 emissions, G_{it} is the provincial per capita GDP, t is the time dimension (t=1995, 1996,..., 2015), β is coefficients, α_i is constant terms, w_{ij} is the spatial weight between the ith province and the jth province, A_{it} is the provincial population divided by area and defined as population densities, E_{it} is the control variables, ε_{it} is the perturbation term that changes with the individual and time, i=1, 2, ..., 30, and n=30. $\sum_{j=1}^{n} w_{ij} C_{jt} = H_1$ [10] Reflects the effects of other provinces' per capita CO2 emissions on the per capita CO2 emissions in a certain province i.

If the ith province and the j province are adjacent, $v_{ij}=1$ and if not, $v_{ij}=0$. The spatial weight matrix is $V=\{v_{ij}\}_{n\times n}$. The row standardization formula is

$$w_{ij} \equiv v_{ij} \Big/ \max\left(1, \sum_{j=1}^{n} v_{ij}\right) \quad (3)$$

In order to avoid the denominator to be zero when standardizing the spatial weight of an island like Hainan, the denominator in Eq. (3) is optimized.

Eq. (2) is a quadratic model. If β1> 0, β2<0, the curve of per capita CO2 emissions and per capita GDP is inverted U-typed. The turning point of per capita GDP can be calculated as [11]

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$$Turning\ point = \exp\left(-\beta_1/2\beta_2\right) \tag{4}$$

3. Results

We employ the panel data regression method which demonstrably takes both the cross-section and time series of the panel data into consideration. As two most common method for estimating coefficients in a regression, both the ordinary least squares (OLS) and generalized least squares (GLS) are suitable for data models with fixed residuals that have the same distribution.

From the results of the empirical FGLS regression analysis in Table 1, the submodels I-IV have considered the spatial effects from adjacent provinces and the population density while the submodels V has not. The significance of each variable of the submodels I-IV is consistent, and there are some differences in coefficients of variables. The submodel IV is selected for the description as the specification tests verify that the panel data are heteroscedastic and serially and spatially dependent. All the explanatory variables affect the explained variable per capita CO2 emissions in natural logarithm significantly at a high level of 99%. The weighted adjacent provinces' per capita CO2 emissions have a significantly positive effect on the provincial per capita CO2 emissions, the carbon emissions of adjacent provinces are mutually affected. Per capita area (Lana) has a significant impact on per capita carbon emission intensity, this means that urbanization exacerbates carbon emissions per capita.

Table 1. FGLS regression results.

	I	II	III	IV	V
	Linear	Panels (hetero)	Panels (correlated)	Panels (core)core(ar1)	Panels (core)core(ar1)
β1	0.608***(0.040)	0.651***(0.028)	0.607***(0.004)	0.326***(0.018)	0.746***(0.018)
β2	-0.059***(0.029)	-0.079***(0.019)	-0.059***(0.002)	-0.074***(0.011)	-0.127***(0.015)
β3	0.344***(0.027)	0.283***(0.016)	0.344***(0.002)	0.652***(0.021)	
β4	-0.205***(0.015)	-0.204***(0.011)	-0.206***(0.001)	-0.3479***(0.019)	
α	-1.038***(0.252)	-0.527***(0.150)	-1.039***(0.016)	-3.0535***(0.203)	1.167***(0.072)

Note: Panels (hetero) stands for the panel-data model with heteroscedasticity across panels. Panels (correlated) means the sub-model allows the correlation and heteroskedasticity across panels. Panels (core) core (ar1) refers to the heteroscedasticity, serial correlation and spatial correlation. Standard errors are in parentheses. *** means p<0.01, ** p<0.05 and * p<0.1.

When it comes to calculating the turning point, the submodel V eliminates the effect of the provincial population density in natural logarithm (Lana) and weighted adjacent provinces' per capita CO2 emissions in natural logarithm (LnH1) on the explained variable (Lync). Regression coefficients of Model are β1=0.746>0 and β2=-0.127<0. In the Chinese provincial panel, the EKC hypothesis assumes that there is an inverted U-shaped relationship named as the first type of EKC between per capita CO2 emissions and per capita GDP. The per capita GDP at the inflection point of the curve is calculated to be 188.6 thousand RMB at constant 2005 price. Chinese fitted turning point of per capita GDP is approximate 4.48 times of its actual value.

From Table 2, it can be concluded that the FGLS results are similar to the PCSE results, and 18 provinces in China have inverted U-shaped curves between per capita CO2 emissions and per capita GDP. These provinces are Beijing, Tianjin, Hebei, Neimenggu, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Shandong, He'nan, Hubei, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, and Qinghai.

Table 3 reports the thresholds of per capita GDP in provinces that meet the first EKC curve under the FGLS and the PCSE estimations, and the thresholds from the two estimators are similar. The provinces that have actually exceeded their own thresholds of per capita GDP in 2015 are Beijing, Tianjin, Shanghai, Zhejiang, Fujian, He'nan, Hubei, Sichuan, and Yunnan. The provinces where the per capita GDPs in 2015 are under their own thresholds are Hebei, Neimenggu, Jiangsu, Anhui, Shandong, Hainan, Chongqing, Guizhou, and Qinghai. There is a large gap between the estimated threshold and actual per capita GDP in Anhui. In addition, there is a linear relationship between per capita CO2 emissions and per capita GDP for the other provinces that do not meet the EKC hypothesis. These provinces increase their per capita CO2 emissions with their per capita GDPs grow up.

Table 2. FGLS and PCSE estimations for each province

Province	FGLS			PCSE		
	α	β1	β2	α	β1	β2
Beijing	0.975***(0.253)	0.929***(0.360)	-0.340***(0.122)	0.969***(0.252)	0.936***(0.357)	-0.342***(0.121)
Tianjin	1.099***(0.177)	1.030***(0.270)	-0.262***(0.092)	1.089***(0.175)	1.044***(0.268)	-0.267***(0.091)
Hebei	1.257***(0.026)	1.210***(0.119)	-0.428***(0.104)	1.256***(0.025)	1.216***(0.118)	-0.432***(0.103)
Shanxi	2.400***(0.036)	0.682***(0.082)	-0.143(0.113)	2.400***(0.036)	0.682***(0.082)	-0.143(0.113)
Neimenggu	1.702***(0.027)	1.670***(0.093)	-0.422***(0.063)	1.702***(0.027)	1.670***(0.093)	-0.422***(0.063)
Liaoning	1.403***(0.049)	0.630***(0.154)	-0.0676(0.088)	1.399***(0.049)	0.643***(0.151)	-0.0732(0.087)
Jilin	1.322***(0.042)	0.691***(0.143)	-0.124(0.115)	1.318***(0.038)	0.705***(0.137)	-0.129(0.110)
Heilongjiang	1.285***(0.027)	0.687***(0.115)	-0.085(0.096)	1.284***(0.026)	0.691***(0.114)	-0.088(0.095)
Shanghai	0.663***(0.190)	1.499***(0.236)	-0.412***(0.071)	0.662***(0.190)	1.500***(0.236)	-0.412***(0.071)
Jiangsu	0.417***(0.097)	1.298***(0.216)	-0.238**(0.097)	0.415***(0.097)	1.301***(0.216)	-0.240**(0.097)
Zhejiang	-0.00396(0.123)	1.992***(0.257)	-0.547***(0.114)	-0.00396(0.123)	1.992***(0.257)	-0.547***(0.114)
Anhui	1.054***(0.033)	0.766***(0.038)	-0.128*(0.070)	1.056***(0.032)	0.769***(0.037)	-0.132*(0.069)
Fujian	-0.116(0.077)	2.251***(0.231)	-0.731***(0.129)	-0.116(0.077)	2.253***(0.230)	-0.732***(0.129)
Jiangxi	0.652***(0.045)	0.728***(0.062)	-0.0388(0.116)	0.652***(0.045)	0.728***(0.062)	-0.0393(0.116)
Shandong	0.582***(0.083)	1.709***(0.251)	-0.427***(0.143)	0.582***(0.082)	1.709***(0.251)	-0.427***(0.143)
He'nan	1.055***(0.045)	1.241***(0.109)	-0.601***(0.134)	1.055***(0.045)	1.242***(0.108)	-0.601***(0.134)
Hubei	1.047***(0.031)	0.907***(0.081)	-0.362***(0.088)	1.047***(0.031)	0.911***(0.080)	-0.365***(0.087)
Hu'nan	0.782***(0.098)	0.758***(0.147)	-0.217(0.210)	0.782***(0.097)	0.759***(0.146)	-0.218(0.210)
Guangdong	0.659***(0.054)	0.424***(0.124)	0.0267(0.077)	0.646***(0.044)	0.460***(0.113)	0.0144(0.070)
Guangxi	0.555***(0.082)	0.645***(0.069)	0.0433(0.108)	0.565***(0.065)	0.669***(0.058)	0.0326(0.096)
Hainan	0.367***(0.090)	1.906***(0.336)	-0.845**(0.410)	0.367***(0.090)	1.906***(0.336)	-0.845**(0.410)
Chongqing	0.952***(0.037)	0.846***(0.098)	-0.246***(0.091)	0.952***(0.037)	0.847***(0.098)	-0.246***(0.090)
Sichuan	1.047***(0.046)	0.975***(0.059)	-0.797***(0.097)	1.047***(0.046)	0.975***(0.059)	-0.797***(0.097)
Guizhou	1.821***(0.021)	0.505***(0.038)	-0.347***(0.049)	1.821***(0.021)	0.505***(0.038)	-0.347***(0.049)
Yunnan	1.189***(0.059)	0.776***(0.072)	-0.706***(0.160)	1.191***(0.058)	0.780***(0.071)	-0.715***(0.159)
Shaanxi	1.101***(0.058)	0.969***(0.103)	0.0241(0.121)	1.101***(0.057)	0.973***(0.102)	0.0216(0.120)
Gansu	1.227***(0.036)	0.687***(0.044)	0.0254(0.094)	1.229***(0.035)	0.689***(0.042)	0.0195(0.092)
Qinghai	1.358***(0.030)	1.018***(0.051)	-0.305***(0.088)	1.358***(0.029)	1.018***(0.051)	-0.305***(0.088)
Ningxia	2.120***(0.110)	1.435***(0.218)	-0.244(0.334)	2.120***(0.110)	1.435***(0.218)	-0.244(0.333)
Xinjiang	1.300***(0.022)	0.778***(0.103)	0.522***(0.104)	1.299***(0.021)	0.787***(0.100)	0.517***(0.102)

Notes: the FGLS estimator assumes the heteroscedasticity across panels and autocorrelation within panels. The PCSE estimator refers to the first-order autocorrelation within panels and allows panel-level disturbances to be heteroscedastic but not contemporaneously correlated.

Table 3. Thresholds of China's provinces meeting EKC.

Province	Thresholds of per capita GDP		Actual per capita GDP	Province	Thresholds of per capita GDP		Actual per capita GDP
	FGLS	PCSE			FGLS	PCSE	
Beijing	3.92	3.929	7.852	He'nan	2.808	2.81	3.234
Tianjin	7.14	7.064	9.523	Hubei	3.5	3.483	3.561
Hebei	4.111	4.085	3.512	Hu'nan			
Shanxi				Guangdong			
Neimenggu	7.233	7.233	5.586	Guangxi			
Liaoning				Hainan	3.089	3.089	2.949
Jilin				Chongqing	5.582	5.593	4.209
Heilong				Sichuan	1.844	1.844	2.848
Shanghai	6.167	6.174	9.268	Guizhou	2.07	2.07	1.833
Jiangsu	15.285	15.036	6.942	Yunnan	1.733	1.725	2.16
Zhejiang	6.177	6.177	6.268	Shaanxi			
Anhui	19.929	18.41	2.729	Gansu			
Fujian	4.663	4.66	5.362	Qinghai	5.306	5.306	2.829
Jiangxi				Ningxia			
Shandong	7.398	7.398	5.401	Xinjiang			

Note: Reported data are the real values at constant 2005 price, not in natural logarithms.

4. Conclusions

In this paper, the results show that there is an EKC between environmental degradation represented by per capita CO2 emissions and economic growth represented by per capita GDP from 1995 to 2015 in China. China's per capita GDP in 2015 does not exceed the threshold of its inflection point (188.6 thousand RMB at constant 2005 price). The CO2 emissions will still increase with the economic development under existing conditions. Chinese fitted turning point of per capita GDP is approximate 4.48 times of its actual value.

There are 18 provinces that meet the inverted U-shaped EKC, among which 9 provinces have exceeded their own thresholds of per capita GDP, entering or approaching the service-oriented economy. They are Beijing, Tianjin, Shanghai, Zhejiang, Fujian, He'nan, Hubei, Sichuan, and Yunnan.

The government could accelerate the process of the low-carbon economy in the 9 provinces where a low-carbon economy has been steadily developing. Hebei, Neimenggu, Jiangsu, Anhui, Shandong, Hainan, Chongqing, Guizhou, and Qinghai could further develop the industry while continuously developing the low-carbon economy. The last taken in considering are provinces which do not meet the EKC hypothesis where industrial economics and low-carbon economy should go hand in hand.

In addition, because the carbon emissions of neighboring provinces affect each other, neighboring provinces should coordinate the implementation of low-carbon development.

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