A projected turning point of China's energy-related CO_2 emissions ----an Environmental Kuznets Curve analysis

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Abstract

The purpose of this paper is to examine whether there is an environmental Kuznets curve (EKC)relationship between China's carbon dioxide (CO_2) per capita and GDP per capita in the period of 1980-2008. The timing of the turning point of China's CO_2 per capitais to be further estimated if an EKC relationship exists. In regression results, anatural logarithm-quadratic relationship is found between CO_2 per capita and GDP per capita which supports EKC hypothesis.In addition, the results also show energy consumption has a significant impact whereas trade openness ratio has an insignificant impact on CO_2 emissions in China.The turning point of CO_2 per capita suggested by the EKC relationshipappears before 2020 which seems earlier than the practicaltrajectory of China's CO_2 emissionsbecause of China's wealth gap and its role in the international trade. Therefore, further efforts could concern reducing domestic income inequality in China and negotiating on making clear responsibilitiesbetween China and developed countries for corresponding CO_2 emissions from China's products exports.

Keywords

carbon dioxide, energy consumption, GDP, trade openness ratio, environmental Kuznets curve

1. INTRODUCTION

China's energy consumption (EC) and relating carbon dioxide (CO_2) emissions have increasing rapidly in the past three decades, especially after the year of 2000 due to an unprecedented high-speed of urbanization and industrialization [1, 2].In 1980-2008, China's GDP increased by 10.08% per annum, energy consumption increased by 5.79% per annum and energy-related CO_2 emissions increased by 5.63% which are shown in Fig. 1, 2 and 3 [3, 4]. Many studies suggest that China's economic development relied heavily on energy consumption, mainly fossil fuels, which represents the major sources of CO_2 emissions [5, 6]. In China's energy structure, fossil fuels, especially coal, dominate the energyconsumption (more than 90%)， and this situation will not change in a short-term [3, 7]. In addition, Chinese exports played an important role of CO_2 emissions and contributed a large amount of CO_2 emissions [8, 9]. The future trend of China's CO_2 emissions has obtained considerable attention from both researchers and policy-makers[10-13].

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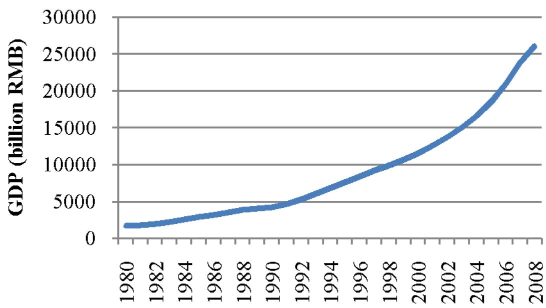

Fig. 1 China's GDP development in 1980-2008
Source: NBSC [3]

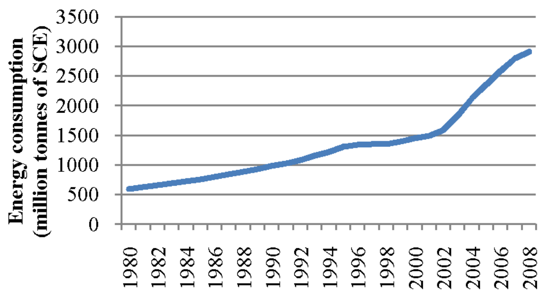

Fig. 2 China's energy consumption in 1980-2008
Source: NBSC[3]

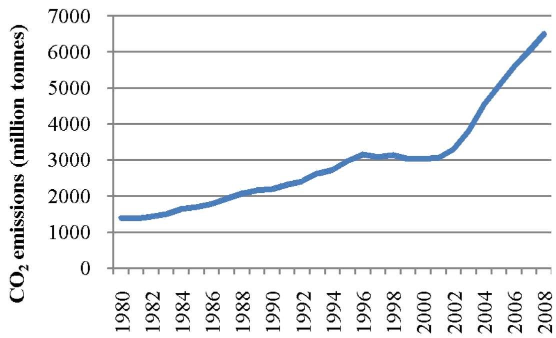

Fig. 3 China's CO2 emissions in 1980-2008
Source: IEA [4]

The Chinese government has emphasised that any CO_2 mitigation strategy must consider China's economic growth. Before the Copenhagen Summit in 2009, Chinese government announced that China would reduce its national CO_2 concentration (CO_2 emissions per unit of GDP) by 40-45% by 2020 compared with the 2005 level [14]. Therefore, the researchon the relationship between China's economic growth and CO_2 emissions is important.

The environment Kuznets curve (EKC)is a hypothesis about the relationship between environmental quality and income per capita.The EKC implies that environmental degradation aggravates as income per capita increases; however, as the income per capita reaches a certain point the environmental degradation begins to decline and eventually an improvement in environmental quality is seen [15-17]. In terms of CO_2 emissions, the EKC hypothesis often refers to an inverted U-shaped curve of CO_2 per capita (CO_2/capita) regarding GDP per capita (GDP/capita), energy consumption per capita (EC/capita), and trade openness ratio. The trade openness ratio is defined as the ratio of the total value of imports and exports to the value of GDP [13, 18-20]. China's population and trade openness ratio in 1980-2008 are shown in Fig. 4 and Fig. 5. The population kept growing at a stable and slow speed within this period due to China's"family planning" policy [21, 22]. The tradeopenness ratio was increasing along an oscillatory trend and reached its highest point in 2006.

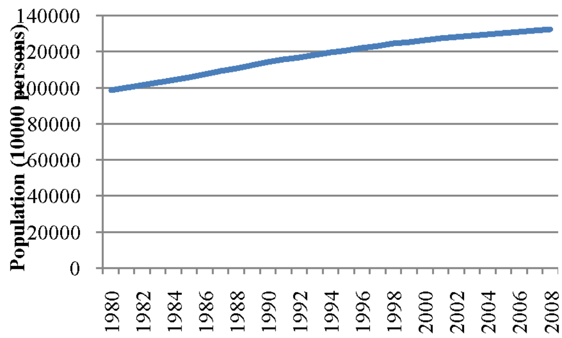

Fig. 4 China's population in 1980-2008
Source: NBSC [3]

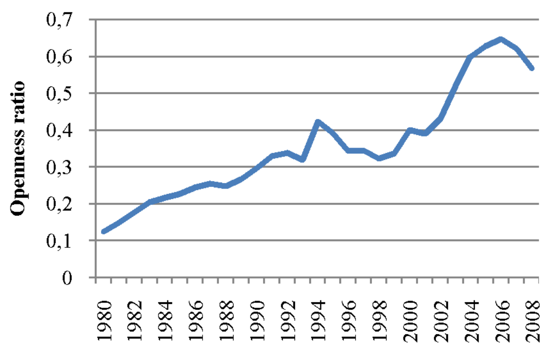

Fig. 5China's trade openness ratio in 1980-2008
Source: calculated from NBSC [3]

The purpose of this paper is to examine whether there is an EKCrelationship between China's CO_2/capita and GDP/capita over the period of

1980-2008. Moreover, the timing of turning point of China's CO_2/capita is estimated. To achieve this purpose, this paper firstly carriesout a natural logarithm (ln)-quadratic regression of China's CO_2/capita regarding China's GDP/capita, EC/capita and trade openness ratio in 1980-2008. Unit root tests, a co-integration analysis and the Granger causality test are applied to ensure the validity of the results. Secondly, it is projected when the turning point of CO_2/capita would occur and the results are discussed.

2. METHOD

To determine the CO_2 EKC, a linear ln-quadratic equation is often adoptedin terms of CO_2/capita regarding GDP/capita, EC/capita and trade openness ratio[13, 18-20, 23, 24]. This study uses the same method, and the logarithm-form of equation is shown as equation (1).

$$\ln CO_2/capita_t = \beta_1 + \beta_2 ln\ GDP/capita_t + \beta_3(ln\ GDP/capita_t)^2 + \beta_4 ln\ EC/capita_t + \beta_5 ln\ openness\ ratio_t + \varepsilon_t \quad (1)$$

In equation (1), t is the year mark from 1980 to 2008, and$\varepsilon$is an regression error term.β_1 is a constant, andβ_2, β_3, β_4 and β_5 are the elasticitycoefficients for GDP/capita, squared GDP/capita, EC/capita and openness ratio, respectively.In a common sense,$\beta_2$should be positive since a higher GDP corresponds to more CO_2 emissions in this case;β_3 would be negative if China's past CO_2 emissions were consistent with the EKC hypothesis;β_4 is expected to be positive because higher energy consumption comes from more economic activities when there have not been significant changes in technology[13, 23, 24]; andβ_5 is expected to be negative in developing countries because they have net exports of energy-intensive products to developed countries [19].

In order to facilitate the regression, equation (1) is adapted to equation (2):

$$y_t = \beta_1(x_1)_t + \beta_2(x_2)_t + \beta_3(x_3)_t + \beta_4(x_4)_t + \beta_5(x_5)_t + \varepsilon_t \quad (2)$$

Where

- y is ln(CO_2/capita);
- x_1 is 1;
- x_2 is ln(GDP/capita);
- x_3 is (ln(GDP/capita))^2;
- x_4 is ln(EC/capita);
- x_5 is ln(openness ratio);
- t is1,2,3,… 29; and
- ε is an regression error term.

To testthe EKC hypnosisregarding China's CO_2 emissions in 1980-2008, the paper firstly carries out unit root tests to verify the stationarityof x_2, x_3, x_4 and x_5, because non-stationary time-seriesvariablescould lead to spurious regression[10, 25]. Next,this paper estimates the coefficients (β_1, β_2, β_3, β_4, β_5) using the Least Square (LS) method.The residual test in the equation is examined to show whether these coefficients are meaningful or not.Then Granger causality testsare applied to distinguish which variables are the causes to CO_2 emissions in China.

3. RESULTS

3.1 Unit root tests of variables

Namely, this study adopts an Augmented Dickey-Full Unit Root Test (ADF-test) and a Dickey-Fuller GLS Test (DF GLS-test) to examine the stationarity of series of y, x_2, x_3, x_4, and x_5.

Table 1 shows that y, x_2, x_3, x_4, and x_5 are not stationary in their level in either the ADF-test or DF GLS test. All the absolute values of the test statistic values are smaller than the absolute values of test critical values which mean the null hypothesis is passed. However, their first differences, D(y), D(x_2), D(x_3), D(x_4), and D(x_5) are stationary which are tested in Table 2. It accords withthe necessary condition of regression. Mind that the absolute values of D(y)'s test statistic is smaller than its test critical value in the ADF-test,whereas it reverses in the DF GLS-test. Because this case has small samples which DF GLS-test is more suitable than ADF-test, so the result of the DF GLS-test is adopted in testing D(y) [26]. According to the unit root tests, all series are concluded at 5% level of significance.

Table 1 Unit root tests of y, x_2, x_3, x_4 and x_5

Null Hypothesis: y, x_2,x_3,x_4,x_5 has a unit root Exogenous: Constant				
	ADF-test		DF GLS test	
	ADF-teststatistic	Test critical values	DF GLS-teststatistic	Test critical values
y	0.011299	-2.627420*	-0.325483	-1.609571*
x_2	1.157102	-2.635542*	-0.107109	-1.609070*
x_3	2.237971	-2.635542*	-0.437871	-1.609571*

x_4	1.408313	-2.642242*	-0.621086	-1.609571*
x_5	-2.275309	-2.625121*	-0.442626	-1.609798*

Table 2 Unit roots tests of D(y), D(x_2), D(x_3), D(x_4) and D(x_5)

Null Hypothesis: D(y), D(x_2),D(x_3),D(x_4),D(x_5) has a unit root				
Exogenous: Constant				
	ADF-test		DF GLS test	
	ADF-teststatistic	Test critical values	DF GLS-teststatistic	Test critical values
D(y)	-2.539827	-2.627420*	-2.214503	-1.953858**
D(x_2)	-4.191091	-3.711457***	-3.423366	-2.656915***
D(x_3)	-3.703812	-2.981038**	-3.044724	-2.656915***
D(x_4)	-2.708539	-2.629906*	-2.753540	-2.656915***
D(x_5)	-4.267594	-3.699871***	-3.982272	-2.653401***

Notes: The method of ADF-test and DF GLS test is LS method. The maximum number of lags is set to six. *, **, *** represent 10%, 5% and 1% level of significance, respectively.

3.2 Co-integration analysis

After unit root tests, a co-integration analysis, for the aim of equation regression, is applied in the serials of y, x_2, x_3, x_4, and x_5. The analysis includes estimating the coefficients in equation (2) by the LS method and testing the residual which is extracted from the regression equation. If the serial of residual is stationary, it means there are co-integration relationships in the serials of y, x_2, x_3, x_4, and x_5 and the coefficients (β_2, β_3, β_4, and β_5) would bemeaningful.

3.2.1 LS method

In this case, the LS method is used to estimate the coefficients. the LS method is applied in equation (2) like following:

For all the observations, we have

$$y = \beta x + \varepsilon \quad (3.1)$$

where

$$y = [y_1, y_2, y_3, y_4, y_5]^T \quad (3.2)$$

$$x = \begin{bmatrix} 1 & \cdots & x_{1,5} \\ \vdots & \ddots & \vdots \\ 1 & \cdots & x_{5,5} \end{bmatrix} \quad (3.3)$$

$$\beta = [\beta_1, \beta_2, \beta_3, \beta_4, \beta_5]^T \quad (3.4)$$

and

$$\varepsilon = [\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4, \varepsilon_5]^T \quad (3.5)$$

By considering the LS method, we have standard solution as

$$\hat{\beta} = (x^T x)^{-1} x^T y \quad (3.6)$$

which we minimized

$$\varepsilon^T \varepsilon \quad (3.7)$$

3.2.2 Estimating the coefficients

Table 3 shows the results of coefficients estimatedby theLS method. As a result, the regression equation (4) is shown like following:

$$y_t = -0.029143 + 1.374964(x_2)_t - 0.066103(x_3)_t + 1.359796(x_4)_t - 0.151044(x_5)_t \quad (4)$$

In order to avoid the spurious regression, the residual of the equation (4) is tested. Firstly, a serial of residual is made from equation (4) in Fig. 6. Secondly, a unit root test is tested in this residual serial in Table 4. The absolute t-statistic of ADF-test is bigger than the absolute test critical values at 1%, 5% and 10% level ofsignificance,respectively, which means the null hypothesis is rejected andthis residual serial is stationary at 1%, 5% and 10% level of significance. Therefore, there are co-integration relationships in the serials of y, x_2, x_3, x_4, and x_5 and the coefficients (β_2, β_3, β_4, and β_5) are meaningful.

Table 3Estimating results of coefficients

Dependent Variable: y				
Method: Least Squares				
Sample: 1980 2008				
Variable	**Coefficient (β)**	**Std.Error**	**t-Statistic**	**Prob.**
x_2	1.374964	0.681286	2.018189	0.0554

x_3	-0.066103	0.040335	-1.638853	0.1149
x_4	1.359796	0.164629	8.259768	0.0000
x_5	-0.151044	0.051155	-2.952696	0.0071
Intercept	-0.029143	0.014073	-2.070793	0.0498
R-squared0.833708		Log likelihood 71.15195		
Adjusted R-squared0.804788		Durbin-Watson stat 2.533347		
S.E. of regression0.021032		F-statistic 28.82782		
Sum squared residual 0.010174		Prob(F-statistic) 0.00000		

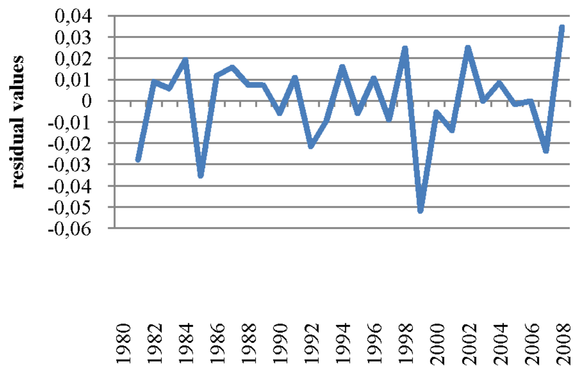

Fig. 6 The serial of residual from equation (4).

Table 4A unit root test of residual serial

Null Hypothesis: Residual has a unit root			
Exogenous: Constant			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-7.511277	0.0000
Test critical values:	1% level	-3.699871	
	5% level	-2.976263	
	10% level	-2.627420	
Augmented Dickey-Fuller Test Equation			
Dependent Variable: D(RESIDUAL)			
Method: Least Squares			
Sample (adjusted): 1981 2008			

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RESIDUAL(-1)	-1.411428	0.187908	-7.511277	0.0000
Intercept	0.000495	0.003423	0.144536	0.8862
R-squared	0.692947	Mean dependent variable		0.002316
Adjusted R-squared	0.680665	S.D. dependent variable		0.031396

Due to $\beta_2>0$ and $\beta_3<0$, there is an inverted U-shaped curve of CO_2/capita regarding GDP/capita which is evidence to support EKC hypothesis and consistency in previous studies [12, 13]. It indicates that GDP/capita growth would improve CO_2/capita mitigation after a certain turning point. Technology improvement and the strongattention to climate change bring the willingness to protect environment and human's health [24]. The value of GDP/capita for the turning point of CO_2/capita could be calculated by$\exp|\beta_2/2\beta_3|$. Therefore, CO_2/capita will occur when the GDP/capita is 31653.88 RMB per capita. Because GDP-capita is 19639.23 RMB per capita which is the highest value in 1980-2008, it means the summit of CO_2/capita has not been reached yet.β_4 is about 1.36 which indicates that a 1% increase in EC/capita will cause a 1.36% increase in CO_2/capita. It means energy consumption has a positive and significant impact on CO_2 emissions. The sign of β_4 is consistent with the expected one and also some previous studies [11-13, 18, 27].β_5 is about -0.15 which indicates that a 1% increase in trade openness ratio will lead to about 0.15% reduction in CO_2/capita. The sign of $\beta_5$accords with the EKC hypothesis in developing countries.Unlike energy consumption, trade openness ratio has an insignificant impact on CO_2 emissions.

3.3 Granger causality test

In this section, the Granger causality test, which is often used for testing causality in income per capita, EC/capita, trade openness ratio and CO_2/capita, is examined to determine whether the variables are causes to CO_2/capita or not [23, 25, 28, 29].

Table 5 shows the pairwise Granger causality test in x_2 and y. When lag is 1, the probabilities of null hypothesis are much bigger than 5% which means that the null hypothesis is not rejected. Therefore, the change of x_2 does not cause the change of y and vice versa. When the lag is bigger than 1, the same result can be obtained. It means that GDP/capita growth is not the cause of CO_2/capita growth overthe period of 1980-2008. Conversely, the growth of CO_2/capita is also not the cause of the growth of GDP/capita. This finding is different from Jalil and Mahmud's results [13]. It might be the case samples are different from their studies.

Table 5 shows the pairwise Granger causality test in x_4 and y. Different from the test in x_2 and y, the probability of "D (x_4) does not Granger cause D(y)" is 0.00573 which is much smaller than 5%. It means the change of x_4 is a cause of the change of y. However, the change of y is not a cause of the change of x_4 because the probability of "D (y) does not Granger cause D(x_4)" is nearly 100%. The same results could be obtained when the lag is larger than 1. Therefore, there is unidirectional causality from EC/capita growth to CO_2/capita growth but not vice versa. The analogousresult is also shown in Shiu and Lam [16] and Yuan et al. [17]. Similarly, Table 6 shows the change of openness ratio is also a cause to CO_2/capita growth but not vice versa. In the studies of Peters et al. [30], Guan et al.[9], and Weber et al. [8], exports is considered as a driver of China's CO_2 emissions which isconsistent in our results.

Table 5 Pairwise Granger Causality Test in x_2 and y

Pairwise Granger Causality Test		
Sample 1980 2008		
Lag=1		
Null Hypothesis	F-Statistic	Prob.
D(x_2) does not Granger Cause D(y)	0.00911	0.92475
D(y) does not Granger Cause D(x_2)	0.95847	0.33734

Table 6 Pairwise Granger Causality Test in x_4 and y

Pairwise Granger Causality Test		
Sample 1980 2008		
Lag=1		
Null Hypothesis	F-Statistic	Prob.
D(x_4) does not Granger Cause D(y)	9.20142	0.00573
D(y) does not Granger Cause D(x_4)	0.00015	0.99033

Table 7 Pairwise Granger Causality Test in x_5 and y

Pairwise Granger Causality Test		
Sample 1980 2008		
Lag=1		
Null Hypothesis	F-Statistic	Prob.
D(x_5) does not Granger Cause D(y)	9.58720	0.00493
D(y) does not Granger Cause D(x_5)	0.14766	0.70417

4. DISCUSSIONS

The results support the EKC hypothesis between China's CO_2/capita and GDP/capita, and the turning point of CO_2/capita will occur when GDP/capita reaches31653.88 RMB per capita. It is thus interesting to know when this turning point will occur.

To forecast this turning point, China's future economic growth should first be determined. The average GDP growth in 1980-2008 was about 10% per annum[3].The slowest increase, more than7% growth per annum, occurred in 1998-1999 when China was involved in the Southeast Asian Financial Crisis [3, 31]. In China's 12th Five-Year Plan (2011-2015), the goal of annual economic growth is set at 7% per annum[32].Thus, China's GDP are projected with the growth rates at7% and 10% per annum, respectively.

In addition, the forecast of China's population is accessed from *China's Low Carbon Development Pathways by 2050-Scenario Analysis of Energy Demand and Carbon Emissions.* China's population isestimated to grow at 0.78% per annum in 2005-2010, 0.57% in 2010-2020, and 0.21% in 2020-2030 [1].

Following the GDP and population growth above, 31653.88 RMB per capita will be reached in 2013-2014 with GDP growth at 10% per annum, or in 2015-2016 when GDP grows by 7% annually according to the results of regression analysis. However, it is difficult to achieve the empiricalprojected turning point before 2020for the practical trajectory of China's CO_2 emissions.There are two reasons to explain.Firstly, China's increasing energy demand and energy consumption willremain increasing in next ten years due to its industrialisation and urbanisation [1]. In addition, China does not have any obligatory mitigation compliance under the current climate change regime. The domestic mitigation target was defined on the basis of CO_2concentration, rather than an absolute amount. Therefore, it is not realistic for China to reach a turning point before 2020 in the currentCO_2 emission trajectory.

Therefore, the turning point of CO_2 per capita suggested by the EKC appears earlier than the practicaltrajectory of China's CO_2 emissions. Firstly, China's wealth gap is one possible reason creating this deviation[15, 33, 34]. The EKC hypothesis implies that environmental degradation begins to decline when people become richer and start to pay more attention to environmental protection and health [35-38]. However, the indicator of GDP per capita cannot reflect the wealth gap in different income levels people. In China, the Gini coefficientreached 0.47 in 2010, which overtook the general warning level at 0.4[33]. This means that a large sum of wealth is owned by a minority of the people, while a majority of thepeople are living with lowincomes. For the majority of the people with lowincomes,they have not yet reached the level to undergo the changes regarding environmental protection. Therefore, the practical turning point in China's CO_2 emissions will occur later than the theoretical projection. Therefore, reducing domestic income inequality would be helpful to reach the turning point of CO_2 emissions fast.

Secondly, China's role in the international trade is another possible reason for the turning point in the EKC projection to appear sooner than in practice. The Hecksher-Ohlin trade theory (H-O theory) suggests that developing countries specialize production of goods that are intensive in labour and nature resources; whereas developed countries would specialize in human capital and manufactured capital intensive activities [34]. Given that labour- and resource-intensive products in general have larger environmental impacts than capital-intensive products, a countrycan avoid environmental degradation by importinglabour- and resource-intensive productsand exporting capital-intensive products. From this point, international trading transfers environmental problems from developed countries to developing countries [34, 36, 38], thus would environmental changes in developing countries in practice be held back longer than theoretical projection implies because they could not transfer environmental problems to other places. As a developing country, China's exports mainly consist of primary goods and manufactured goods which are mainly intensive in energy and carbon[3]. Wang and Watson [39] show that China's net exports accounted for 23% of its total CO_2 emissions in 2004. Guan et al. [9] suggest that the growth in exports is one of the main forces driving the increase of China's CO_2 emissions. Therefore, the turning point suggested by the CO_2EKC relationshipappears sooner than the practical trajectory in China's CO_2 emissions. Therefore, more international negotiations are need between China and developed countries. For instance, the developed countries who imports energy and carbon intensive products from China should be responsible for the correspondingemissions and provide funds and technologies for China's CO_2 emissions mitigation.

5. CONCLUSIONS

This paper examinedthe relationship between China's CO_2/capita and GDP/capita in 1980-2008. The results indicate that there is an EKC relationship between the CO_2/capita and the GDP/capita in the period of 1980-2008. While, energy consumption has a significant impacton CO_2 emissions and trade openness ratio has an insignificant impact on CO_2 emissions. Moreover, the EKC projection suggest the turning point in China's CO_2/capita would occur in 2013-2014 with GDP growth at 10% per annum, or in 2015-2016 when GDP grows by 7% annually. However, this projectionmay appear sooner than the practical trajectory in China's CO_2 emissionsbecause of China's wealth gap and its role in international trade. Therefore, further efforts could concern domestic income inequality reductionand international negotiations on making clear responsibilities between China and developed countries for corresponding CO_2 emissions from China's products exports.

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