

A projected turning point of China's CO₂ emissions

---an analysis of Environmental Kuznets Curve for China

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Abstract:

This paper examines the possible existence of an Environmental Kuznets Curve (EKC) relationship between China's carbon dioxide (CO₂) emissions per capita (CO₂/capita) and GDP per capita (GDP/capita) in 1980-2008. The timing of the turning point in China's CO₂/capita can be further estimated if an EKC relationship exists. In regression results, a natural logarithm-quadratic relationship was found between CO₂/capita and GDP/capita, which supports the EKC hypothesis.

However, China's CO₂ emissions are still on a growing track until around 2078 in the empirical analysis. More importantly, CO₂ emissions will not spontaneously decrease if China continues to develop its economy without adopting instruments for mitigating climate change. China's wealth gap and its role in international trade are discussed as two possible factors to affect EKC hypothesis. Therefore, domestic income inequality reduction and international negotiations to allocate clear responsibilities between China and developed countries for CO₂ emissions associated with China's product exports are suggested to the further efforts.

Keywords: Carbon dioxide (CO₂); primary energy consumption; GDP; trade openness ratio; Environmental Kuznets Curve (EKC).

1. Introduction

China's primary energy consumption (EC) and carbon dioxide (CO₂) emissions have been increasing rapidly for the past three decades, especially since 2000, due to an unprecedented high rate of urbanisation and industrialisation (National Development and Reform Commission, 2009; Jiang et al., 2009). In 1980-2008, China's GDP increased by 10.08% per annum, energy consumption increased by 5.79% and CO₂ emissions increased by 5.63%, as shown in Figures 1, 2 and 3 (National Bureau of Statistics of China, 2010; IEA, 2010). Many studies suggest that China's economic development relies heavily on primary energy consumption, mainly fossil fuels, which represent the major source of CO₂ emissions (Gregg et al., 2008; Dai and Bai, 2009). In China's primary energy consumption structure, fossil fuels, especially coal, dominate energy consumption (more than 90%) and this situation will not change in the short-term (National Bureau of Statistics of China, 2010; Xu et al., 2010). In addition, Chinese exports play an important role for CO₂ emissions and contribute a large amount of CO₂ emissions (Weber et al., 2008; Guan et al., 2008). The future trend in China's CO₂ emissions has attracted considerable attention from both researchers and policy-makers (Chen and Liu, 2004; Du et al., 2007; Lin and Jiang, 2009; Jalil and Mahmud, 2009).

The Chinese government has emphasised that any CO₂ mitigation strategy must consider China's economic growth. Before the Copenhagen Summit in 2009, the Chinese government announced that China would reduce its national CO₂ concentration (CO₂ emissions per unit of GDP) by 40-45% by 2020 compared with the 2005 level (Fu et al., 2009). Therefore, the research on the relationship between China's economic growth and CO₂ emissions is important.

The Environmental Kuznets Curve (EKC) is a hypothesis concerning the relationship between environmental quality and income per capita. The EKC implies that environmental degradation is aggravated as income per capita increases. However, once the income per capita reaches a certain point, the environmental degradation begins to decline and eventually an improvement in environmental quality is seen (Kuznets, 1955; Shiu and Lam, 2004; Yuan et al., 2007). In terms of CO₂ emissions, the EKC hypothesis often refers to an inverted U-shaped curve of CO₂ per capita (CO₂/capita) regarding GDP per capita (GDP/capita), primary 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 (Auffhammer and Carson, 2008; Halicioglu, 2009; Jalil and Mahmud, 2009; Sun et al., 2010). China's population and trade openness ratio in 1980-2008 are shown in Figures 4 and 5, respectively. The population kept growing at a stable and slow speed within this period due to China's family planning policy (Rajeswar, 2000; Ding and Hesketh, 2006). The trade openness ratio increased along an oscillatory trend and reached its highest point in 2006.

The objective of this study was to examine whether there is an EKC relationship between China's CO₂/capita and GDP/capita during the period 1980-2008 and to estimate the timing of the turning point in China's CO₂/capita. To achieve this objective, a natural logarithm (ln)-quadratic regression of China's CO₂/capita was carried out regarding China's GDP/capita, EC/capita and trade openness ratio in 1980-2008. Unit root tests and a co-integration analysis were applied to ensure the validity of the results. The results were then used to project when the turning point in CO₂/capita would occur and the findings were discussed.

2. Method

To determine the CO₂ EKC, a linear ln-quadratic equation is often adopted in terms of CO₂/capita regarding GDP/capita, EC/capita and trade openness ratio (Ang, 2007; Auffhammer and Carson, 2008; Halicioglu, 2009; Jalil and Mahmud, 2009; Atici, 2009; Sun et al., 2010). This study used the same method with the following logarithm form of the equation:

$$\begin{aligned} \ln(CO_2/capita)_t &= \beta_1 + \beta_2 (\ln GDP/capita)_t + \beta_3 [(\ln GDP/capita)_t]^2 + \beta_4 (\ln EC/capita)_t \\ &+ \beta_5 (\ln trade\ openness\ ratio)_t + \varepsilon_t \quad (1) \end{aligned}$$

where t is year from 1980 to 2008, ε is the regression error term. β_1 is a constant, and β_2 , β_3 , β_4 and β_5 are the elasticity coefficients for GDP/capita, squared GDP/capita, EC/capita and openness ratio, respectively. In a common sense, β_2 should be positive since a higher GDP corresponds to more CO₂ emissions in this case; β_3 would be negative if China's past CO₂ 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 (Ang, 2007; Atici, 2009); and β_5 is expected to be negative in developing countries because they have net exports of energy-intensive products to developed countries (Halicioglu, 2009).

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

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

where

- y is ln(CO₂/capita)
- x₁ is 1

- x_2 is $\ln(\text{GDP/capita})$
- x_3 is $[\ln(\text{GDP/capita})]^2$
- x_4 is $\ln(\text{EC/capita})$
- x_5 is $\ln(\text{openness ratio})$
- t is $1, 2, 3, \dots, 29$
- ε is an regression error term.

To test the EKC hypothesis regarding China's CO₂ emissions in 1980-2008, unit root tests were carried out to verify the stationarity of y , x_2 , x_3 , x_4 and x_5 , because non-stationary time-series variables could lead to spurious regression (Chen and Liu, 2004; Soytaş et al., 2007). The coefficients (β_1 , β_2 , β_3 , β_4 , and β_5) were then estimated using the Least Square (LS) method. The residual test in the equation was examined to determine whether these coefficients were meaningful or not.

3. Results

3.1 Unit root tests of variables

An Augmented Dickey-Full (ADF) unit root test was used to examine the stationarity of series of y , x_2 , x_3 , x_4 , and x_5 .

Table 1 ADF test of y , x_2 , x_3 , x_4 and x_5

Null Hypothesis: y , x_2 , x_3 , x_4 and x_5 has a unit root		
Exogenous: Constant		
	ADF test statistic	Test critical values
y	0.011299	-2.627420*
x_2	-0.448039	-2.642242*
x_3	1.847154	-2.635542*
x_4	1.360692	-2.638752*
x_5	-1.706201	-2.625121*

Notes: The LS method was used in the ADF test; the maximum number of lags was set to six; * represent 10% level of significance.

Table 2 ADF test of $D(y)$, $D(x_2)$, $D(x_3)$, $D(x_4)$ and $D(x_5)$

Null Hypothesis: $D(y)$, $D(x_2)$, $D(x_3)$, $D(x_4)$ and $D(x_5)$ has a unit root		
Exogenous: Constant		
	ADF test statistic	Test critical values
$D(y)$	-2.639827	-2.627420*
$D(x_2)$	-3.887350	-3.737853***
$D(x_3)$	-2.938401	-2.635542*
$D(x_4)$	-3.038738	-2.998064**
$D(x_5)$	-4.514928	-3.699871***

Notes: The LS method was used in the ADF test; the maximum number of lags was set to six; *, **, *** represent 10%, 5% and 1% level of significance, respectively.

As shown in Table 1, the null hypothesis was rejected for all variables, i.e. the absolute values of the ADF test statistical values were smaller than the absolute values of test critical values, and this means that all variables are not stationary at 10% level of significance. Therefore, the first order differences of each variable were calculated and examined in the stationarity test.

The first order differences of each variable were stationary at 10% level of significance, i.e. the absolute values of the ADF test statistical values were larger than the absolute values of test critical

values (Table 2). Therefore, the cointegration analysis was carried out using the Engle-Granger method (Engle and Granger, 1987).

3.2 Co-integration analysis

After the unit root tests, a co-integration analysis, for the equation regression was, applied in to the series of y , x_2 , x_3 , x_4 , and x_5 . The analysis included estimating the coefficients in equation (2) by the LS method and testing the residual extracted from the regression equation. If the series of residuals is stationary, it this means there are co-integration relationships in the series of y , x_2 , x_3 , x_4 , and x_5 and the coefficients (β_2 , β_3 , β_4 , and β_5) would be meaningful.

3.2.1 LS method

In this case, the LS method was applied to equation (2) to estimate the coefficients as follows:

For all 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 the standard solution as:

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

which we minimised to:

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

3.2.2 Estimating the coefficients

Table 3 Results of regression

Dependent Variable: y				
Method: Least Squares				
Sample: 1980 2008				
Variable	Coefficient (β)	Std. Error	t-Statistic	Prob.
x_2	0.6924	0.237136	2.919764	0.0075
x_3	-0.0459	0.014349	-3.201483	0.0038
x_4	1.4008	0.099343	14.10037	0.0000
x_5	-0.1770	0.048334	-3.662072	0.0012
Intercept (x_1)	-4.4647	1.589039	-2.950054	0.0070
R-squared	0.996			

Table 3 shows the results of coefficients estimated by the LS method. The resulting regression equation is as follows:

$$y_t = -4.4647 + 0.6924(x_2)_t - 0.0459(x_3)_t + 1.4008(x_4)_t - 0.1770(x_5)_t \quad (4)$$

In order to avoid spurious regressions, the residual of equation (4) was tested. First, a series of residuals was made from equation (4). Then a unit root test was applied to this series of residuals (Table 4). The absolute t-statistic of the ADF test was larger than the absolute test critical values at 10% level of significance, which means that the null hypothesis is rejected and this series of residuals is stationary at 10% level of significance. Therefore, there are co-integration relationships in the series 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. In addition, the values of the coefficients are congruent with the above analysis, namely $\beta_2 > 0$, $\beta_3 < 0$, $\beta_4 > 0$, and $\beta_5 < 0$ which is the evidence to support the EKC hypothesis.

Table 4 ADF test of residuals

Null Hypothesis: the series of residuals has a unit root		
Exogenous: Constant		
Method: Least Squares		
Dependent Variable: D(residuals)		
Sample: 1980 2008		
Included observations: 29		
		t-Statistic
		Prob.
ADF test statistic		-2.963384
		0.0509
Test critical values:	1% level	-3.689194
	5% level	-2.971853
	10% level	-2.625121

4. Empirical analysis

The EKC hypothesis indicates that the stationary point of the CO₂/capita to the factor of GDP/capita appears when the GDP/capita reaches the level of $\exp|\beta_2/2\beta_3|$, i.e. 1874 RMB according to Equation

4. Considering the value in practice, China's GDP per capita was 1864 RMB in 1981 and reached 2001 RMB in 1982, and this means that the stationary point was attained in 1982.

The verification of the EKC hypothesis and the attainment of the stationary point indicate that the growth in GDP has become a declining force for CO₂ emissions after 1982. However, China's CO₂ emissions will continue to increase in the next several decades. The reasons include that CO₂ emissions are simultaneously affected by other factors than GDP, such as primary energy consumption and international trade, which will continue to grow. Given that the coefficients in the linear logarithmic-quadratic model demonstrate the elasticity of CO₂ emissions per capita (Chen and Zhang, 2008; Granger, 1986), the impacts of primary energy consumption on CO₂ emissions are greater than GDP, i.e. CO₂ emissions will increase by around 1.4% when primary energy consumption increases by 1%, while emissions will increase by less than around 0.69%, or even decrease, when GDP increases by 1%.

The turning point of overall CO₂/capita to the factors of GDP/capita, EC/capita and trade openness ratio is estimated further. In order to give a rough sense of the turning point, a projection was carried out in this study. To simplify calculations, it is assumed that: (1) the growth in GDP is 10% per annum; (2) population and primary energy consumption will increase at the same speed as their average levels in the past; and (3) trade openness ratio will remain at the average level. As a result, China's CO₂ emissions will continue to grow in a very long period and the turning point in overall CO₂ emissions will appear in 2078.

Comparing the results with other studies, most studies found that China's CO₂ emissions and GDP can be cointegrated, or in other words, there is a long-term relationship between CO₂ emissions and GDP (Yaguchi et al., 2007; Wang et al., 2011; Jalil and Mahmud, 2009; Han and Lu, 2009). However, whether the EKC hypothesis is true and especially when the turn point would appear, when the EKC hypothesis is verified, remain debateable and the answers highly depend on what impact factors and what data are used (Dinda, 2004; Stern, 2004). Using the mostly studied macroeconomic factors and time-series data in the period of 1980-2008, this study found the existence of an EKC relationship between CO₂ emissions per capita and GDP per capita. It is noted that, up to now, there have been only a little more than three decades since the reform and opening up policy was launched in China and from an econometrics perspective a regression can be more stable if a longer period of statistical data were available. In addition, different results can be produced if panel data were adopted, e.g. Yaguchi et al. (2007) and Wang et al. (2011).

5. Discussions

As regards EKC hypothesis of CO₂ emissions in China, there are two points which are discussed. Firstly, China's wealth gap is creating this deviation (Kuznets, 1955; Chen, 2010; Stern, 1998). 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 (Heckscher et al., 1991; Arrow et al., 1996; National Bureau of Statistics of China, 2010; Stern Michael and David, 1996). However, the indicator of GDP per capita cannot reflect the wealth gap in different income levels. In China, the Gini coefficient reached 0.47 in 2010, which overtook the general warning level at 0.4 (Chen, 2010). This means that a large proportion of wealth is owned by a minority of the people, while the majority of the people are living on low incomes. Thus the latter have not yet reached the level at which they would display changes regarding environmental protection. Therefore, reducing domestic income inequality would be helpful in reaching the turning point of CO₂ emissions more rapidly.

Secondly, China's role in international trade is another discussed point. The Heckscher-Ohlin (H-O) trade theory suggests that developing countries tend to specialise in production of goods that are intensive in labour and nature resources, whereas developed countries specialise in activities that are intensive in human capital and manufacturing capital (Stern, 1998). Given that labour- and resource-intensive products in general have larger environmental impacts than capital-intensive products, a country can avoid environmental degradation by importing labour- and resource-intensive products and exporting capital-intensive products. From this viewpoint, international trading transfers environmental problems from developed countries to developing countries (Arrow et al., 1996; Stern Michael and David, 1996; Stern, 1998). Thus environmental changes in developing countries in practice would 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 (National Bureau of Statistics of China, 2010). Wang and Watson (2007) show that China's net exports accounted for 23% of its total CO₂ emissions in 2004. Guan et al. (2008) suggest that the growth in exports is one of the main forces driving the increase in China's CO₂ emissions. It is clear that more international negotiations are needed between China and developed countries so that for instance the developed countries that import energy- and carbon-intensive products from China take responsibility for the relevant emissions and provide funds and technologies for China's CO₂ emissions mitigation.

6. Conclusions

Examination of the relationship between China's CO₂/capita and GDP/capita in the period 1980-2008 showed that there was an EKC relationship between CO₂/capita and GDP/capita in that period. However, China's CO₂ emissions are still on a growing track until around 2078 in the empirical analysis. The analysis of the EKC hypothesis only concerns the statistical relationship between empirical CO₂ emissions and their impact factors in principle, rather than a fundamental theorem predicting a fact that will occur regardless. This means that the relationship based on data in the past can be changed and a new relationship can be established when new statistics are available. More importantly, CO₂ emissions will not spontaneously decrease if China continues to develop its economy without adopting instruments for mitigating climate change; on the other side, CO₂ emissions could start to decrease if substantial efforts are made.

China's wealth gap and its role in international trade are discussed as two possible factors to affect EKC hypothesis. Therefore, domestic income inequality reduction and international negotiations to allocate clear responsibilities between China and developed countries for CO₂ emissions associated with China's product exports are suggested to the further efforts.

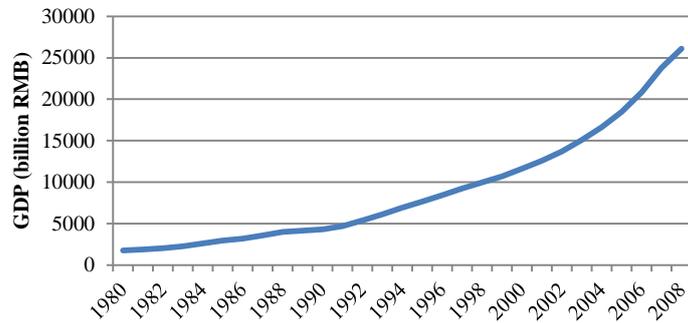
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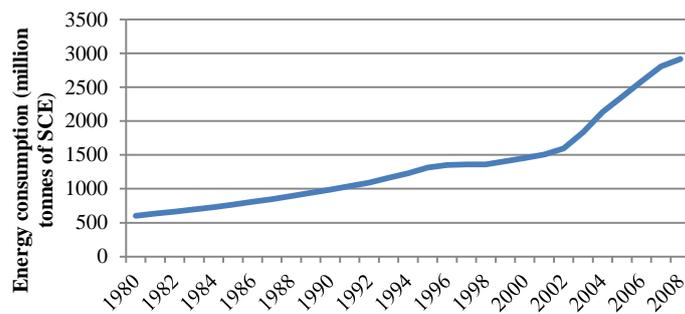
Figure 1-5

Figure 1 China's GDP, 1980-2008



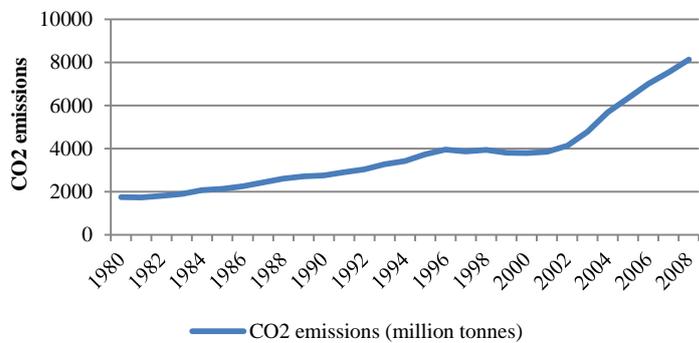
Source: National Bureau of Statistics of China (2010)

Figure 2 China's energy consumption, 1980-2008



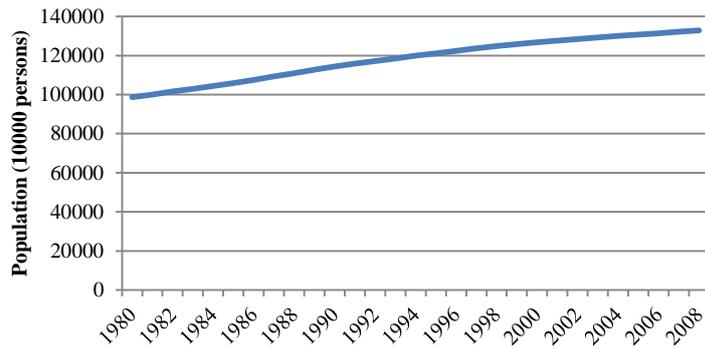
Source: National Bureau of Statistics of China (2010)

Figure 3 China's CO₂ emissions, 1980-2008



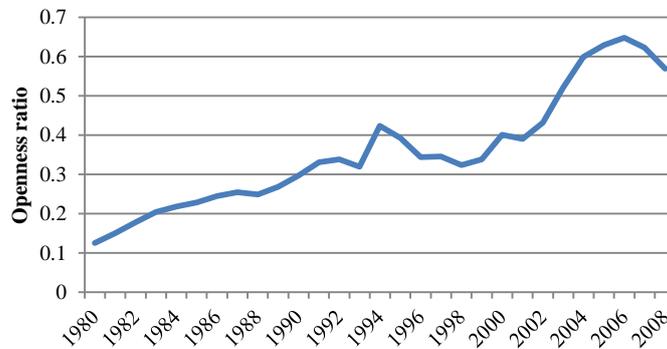
Source: International Energy Agency (2010)

Figure 4 China's population, 1980-2008



Source: National Bureau of Statistics of China (2010)

Figure 5 China's trade openness ratio, 1980-2008



Source: calculated from National Bureau of Statistics of China (2010)