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Halkos, George and Tzeremes, Nickolaos

University of Thessaly, Department of Economics

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George Emm. Halkos* **and Nickolaos G. Tzeremes**

University of Thessaly, Department of Economics,

Korai 43, 38333, Volos, Greece

Abstract

Using time series data, this paper investigates China's carbon emissions during 1960-2006, with particular focus on the direct role of growth and in connection to trade and the value added by various sectors like agriculture, industry and services. Our empirical results indicate the presence of an inverted U-shaped curve between CO_2 emissions and growth represented by the GDP per capita. Trade seems to be an important determinant in this relationship.

Keywords: CO_2 emissions; Economic growth; Trade; Environmental kuznets curve; China.

JEL classification codes: C22, C51, O10, Q56

*Address for Correspondence: Department of Economics, University of Thessaly, Korai 43, 38333, Volos, Greece. Email: halkos@econ.uth.gr, URL: http://www.halkos.gr/, Tel.: 0030 24210 74920, FAX: 0030 24210 74701

1. Introduction

China's rapid economic growth has caught the attention of economists, researchers and politicians around the world. China is one of the largest economies in the world and, since its economic reform in 1978 GDP rises on an average above 9%. According to Holtz (2008), in 2002 the USA economy was eight times bigger than the Chinese economy in terms of GDP, while in 2004 was only seven times bigger. But he states that if we take into account the Penn World Tables, the USA economy is less than twice as bigger as the Chinese in terms of purchasing power. If this rise in economic growth continues then the Chinese economy will surpass the USA economy in terms of purchasing power in about five years, while in about fifteen years China will be the world's largest economy. Holtz (2008) argues that according to demographics, which measure the quality and quantity of labor, China's growth will continue to increase for another twenty to forty years.

Plenty of reasons exist explaining this rapid economic growth. Zhao and Wang (2009) reviewed the policy changes after China's WTO accession as well as the existing literature on China's trade and economic development in order to frame the Chinese success and infer some basic rules for decision-makers in China and other developing countries. As Chen and Feng (2000) state, the determinants of China's economic growth, among others, are human capital, which is significant for developing countries in order to achieve economic growth, trade, fertility rate, political stability and government's financial and political decisions.

The most significant determinant of China's rapid economic growth is openness of trade. In 2006, 60% of China's GDP is represented by exports and imports (He, 2010). In 2008, China became the second largest trading nation, above Germany, and it is very likely to exceed the USA in the near future (Yan and Yang, 2010). However, economic growth plus trade openness are considered responsible for environmental degradation. A remarkable observation is that economic growth affects China's provinces in a quite different manner (Chen and Feng, 2000).

As implied above, economic development in China has raised a number of issues such as income inequality, diminishing natural resources, environmental degradation and infrastructure problems (Wen and Chen, 2008). Moreover, they have developed the Net Progress Proceed (NPP), an index which measures the sustainability of an economy. They apply NPP on the Chinese economy and according to their results, if no further policy is implemented to promote public welfare, then the costs of economic growth will be greater than its benefits resulting from unsustainable development. The results of an unsustainable development are confirmed by Hong et al. (2007) who measure ecological footprint and ecological deficit of China.

Environmental degradation, as mentioned, appears to be the most significant problem that economic growth has caused. Sixteen out of twenty world's most polluted cities are Chinese, while two-thirds of Chinese cities fail to meet air quality standards and over three-fourths of urban population lives in an air-polluted city (He, 2010). China emits various pollutants in high intensity and is the second largest emitter of greenhouse gasses in the world (Guo et al., 2010). China's NOx emission load per unit of GDP is almost twenty eight times bigger than Japan's and three times bigger than India's and SO_2 emission load per unit of GDP is almost sixty nine and twenty six times bigger than Japan's and Germany's respectively (Wen and Chen, 2008).

The most significant greenhouse gas is CO_2 as it is responsible for seventy two percent of global warming effects (Yan and Yang, 2010). Since, China is the world's largest emitter of CO_2 (Auffhammer and Carson, 2008), showing an increasing trend over the past fifty years (Feng et al., 2009), it affects global environment extensively. In 2007, China's CO_2 emissions increased by eight percent nationally which accounted for the two-thirds of the global increase of CO_2 (Yan and Yang, 2010). According to Zhang and Cheng (2009), the rapid economic growth the period after the economic reform until today has led to an increase in energy consumption of about 340% and of CO_2 about the same level. Based on the above, it is clearly understandable why the absence of developing countries in the Kyoto Protocol has raised many questions.

In 1997, the Kyoto Protocol was signed by industrialized Annex B countries in order to reduce greenhouse gasses by at least five percent, although it does not include industrialized Non-Annex B countries (Bastianoni et al., 2004). The lack of inclusion of Non-Annex B countries, especially China and India, constitutes a major threat for the planet and their participation in a future agreement, after 2012 expiring of the Kyoto Protocol, is considered vital (Pittel and Rubbelke, 2008).

Previous studies on China's carbon emissions focus mainly on the continuously increasing emissions till the middle of the 1990s, the stability of emissions from 1996 to 2001 and the rise in emissions since 2002. China showed a noticeable reduction in energy intensity from the beginning of its economic reform in 1978 till 2000, but since then this rate of decline was slowed and since 2003 energy intensity is increasing. The majority of previous studies showed that most of this reduction was caused by technological change and disagrees with the role of structural change (Ma and Stern, 2007). Our paper explores China's carbon emissions during 1960-2006 focusing on the role of growth, trade and the value added by various sectors like agriculture, industry and services. Our empirical results indicate the presence of an inverted U-shaped curve between CO_2 emissions and growth represented by the GDP per capita.

The structure of the paper is the following. Section 2 presents the data used in our analysis while the next section discusses the proposed method of analyzing the data set. Section 4 discusses the empirical results derived and the last section concludes the paper commenting on the policy implications of the empirical findings.

2. Description of variables

A number of variables for the period 1960-2006 were considered in our analysis. The dependent variable is the carbon dioxide (CO_2) emissions (metric tons per capita) produced by burning fossil fuels as well as by the cement manufacture. They include carbon dioxide produced from the consumption of solid, liquid and gas fuels.[1]

Growth is accounted by the Gross Domestic Product per capita (GDPc in current US$) which is defined as GDP divided by mid-year population. Agriculture value added (as a % of GDP) corresponds to the International Standard Industrial Classification (ISIC) divisions 1-5 and includes forestry, hunting, fishing, cultivation of crops and livestock production. As value added we mean the net output of a sector after adding-up all outputs and subtracting intermediate inputs. Industry value added (as a % of GDP) corresponds to ISIC divisions 10-45 and refers to manufacturing (ISIC divisions 15-37). It consists of the value added in mining, manufacturing, construction, electricity, water, and gas. Services value added (as a % of GDP) refers to ISIC divisions 50-99 and include value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, personal services (education, health care, and real estate services) and imputed bank

[1] The source of this data is the Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States.

service charges, import duties, and any statistical discrepancies noted by national compilers as well as discrepancies arising from rescaling.

The values of trade are expressed by imports and exports of commodities. Specifically, imports/exports of commodities (as % of GDP) represent the value of all commodities received/provided from/to the rest of the world (value of merchandise, freight, insurance, transport, travel, royalties, license fees, and other services, like communication, construction, financial, information, business, personal, and government services). They exclude compensation of employees and investment income and transfer payments.[2]

3. Methodology

These variables were used to develop a regression model. Table 1 presents the descriptive statistics while Figure 1 shows the time series graphs of all the variables into consideration. Table 2 presents the unit root tests for the variables considered. As can be seen all variables are I(1) in first differences and I(0) in levels. We have also tried to see if they are co-integrated. The result of the Engle-Granger test confirms co-integration among the variables as shown at the bottom of Table 2.

Table 1: Descriptive statistics of the variables considered

	CO_2	EXPORT	GDPC	IMPORT	INDVA	SERVA	TRADE
Mean	1.853843	112670.2	428.3366	101015.9	42.94164	29.68093	11654.33
Median	1.628020	22321.00	223.2519	22014.00	44.37922	28.71132	540.2600
Maximum	4.652144	968978.0	2027.338	791461.0	48.67889	41.46745	177517.0
Minimum	0.573794	1913.230	69.78987	1372.970	31.18217	21.60331	-12215.0
Std. Dev.	0.995706	203589.6	467.9292	175717.6	4.823697	6.323631	31152.95
Observations	47	47	47	47	47	47	47

[2] The source of all these data is the World Bank national accounts data, and OECD National Accounts data files.

Table 2: Unit root Dickey-Fuller tests (with intercept)

logCO_2	**logGDPc**	**logGDPc^2**	**logGDPc^{3-}**
-0.16764 [0.9348]	2.3635 [1.0000]	3.65803 [1.0000]	5.2194 [1.0000]
ΔlogCO$_2$	**ΔlogGDPc**	**ΔlogGDPc^2**	**ΔlogGDPc^3**
-5.1469 [0.0001]	-5.8308 [0.0000]	-4.9265 [0.0002]	-.3.8291 [0.0052]
logSerVA	**logExport**	**logAgrVA**	**logIndVA**
-0.5974 [0.8609]	0.8878 [0.9945]	0.6444 [0.9895]	-2.5615 [0.1084]
ΔlogSerVA	**ΔlogExport**	**ΔlogAgrVA**	**ΔlogIndVA**
-4.8341 [0.0003]	-3.9092 [0.0043]	-8.7434 [0.0000]	-8.73244 [0.0000]
Engle-Granger			
-8.0086 [0.0000]			

The DF test without and with intercept and trend gave similar results.

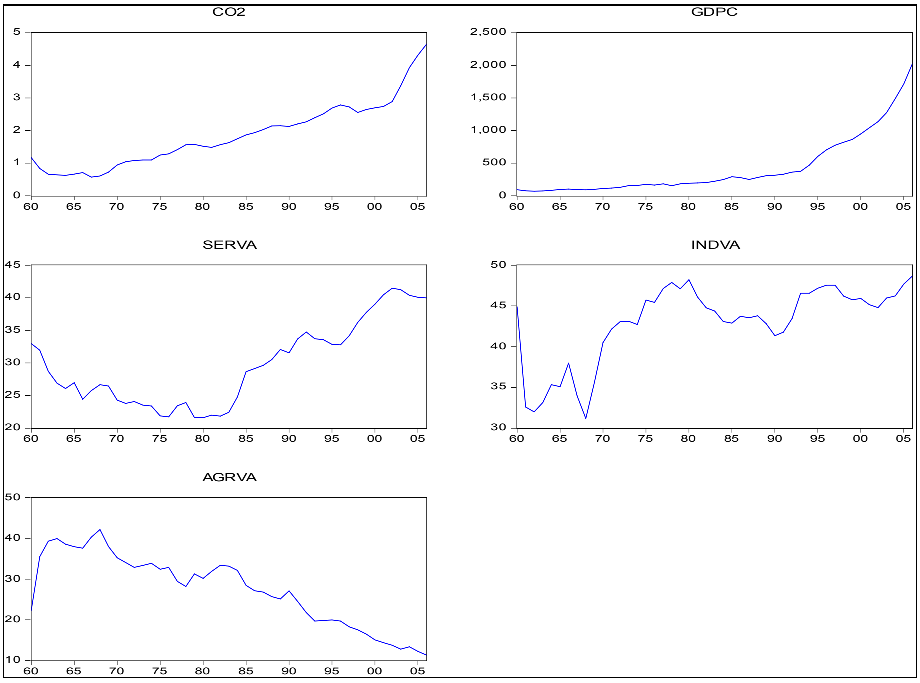

Figure 1: Time series plots

As our main interest is in terms of the main effects we have ignored interactions. Working with the most statistically significant variables we derive the form of the fitted model, which may be represented as

$$CO_2 = \beta_0 + \beta_1 \text{ GDPc} + \beta_2 \text{ GDPc}^2 + \beta_3 \text{ Trade} + \beta_4 \text{ AgrVA} + \beta_5 \text{ IndVA} + \beta_6 \text{ SerVA} + \varepsilon_t$$

where CO_2 is the dependent variable and GDPc, Trade, agriculture value added (AgrVA), industry value added (IndVA) and services value added (SerVA) the explanatory variables. ε_t is the disturbance term. All variables are in logarithmic form.

In all model formulations we faced problems of serial correlation. In such cases, techniques for estimating AR models, like the Cochrane-Orcutt, Prais-Winsten, Hatanaka, and Hildreth-Lu procedures, are multi-step approaches designed in a way to make feasible the estimation by using standard *linear* regression. But these approaches have significant drawbacks when working with models containing lagged dependent variables as explanatory variables or models of higher-order AR specifications (Davidson and MacKinnon, 1993; Greene, 2008).

Here we estimate AR models using nonlinear least squares estimates, which are asymptotically efficient and equivalent to maximum likelihood estimates. To estimate an AR(p) model we transform the linear model,

$$y_t = x_t^{'}\beta + \varepsilon_t$$

With AR(p) errors

$$\varepsilon_t = \rho_1 \varepsilon_{t-1} + ... + \rho_p \varepsilon_{t-p} + u_t$$

into the nonlinear model:

$$y_t = (\rho_1 y_{t-1} + \rho_2 y_{t-2} + ... + \rho_p y_{t-p}) + f(x_t, \beta) - \rho_1 f(x_{t-1}, \beta) - \rho_2 f(x_{t-2}, \beta) - ... - \rho_p f(x_{t-p}, \beta) + u_t$$

and we estimate it using nonlinear least squares. The autocorrelation coefficients (ρ_i) and the slopes (β_i) are estimated simultaneously using a Marquardt nonlinear least squares algorithm to the transformed equation, which modifies the Gauss-Newton algorithm by adding a correction matrix to the Hessian approximation (Fair, 1984; Davidson and MacKinnon, 1993). The empirical results derived are presented next.

4. Empirical results

The results of the fitted models are presented in Table 3. The first column in this table presents the results of the reduced form of the model where we may see the direct impact of growth measured by GDPc on CO_2. The next columns represent the full model where we have either all the variables considered in the analysis (column 4) or two other forms with the statistically significant variables.

In all cases we have a very high level of predictability (around 99%) and an inverted U-shaped curve between carbon dioxide emissions and growth. The constant term is significant for all levels in the first two models, significant for 10% in the third model and insignificant in the last model. The GDPc is fully significant in the first and last models formulation, only at 10% in the second and insignificant in the third model. The squared tem of GDPc is significant at 10% in the first model, at 5% in the second model, insignificant in the third model and fully significant in the last model formulation.

Similarly the trade variable in the form of exports has a positive effect and it is statistically significant in all model formulations and for all the conventional levels of statistical significance. In terms of the sector variables, we can see that the service value added variable has a negative influence (as expected) and it is fully significant in the last model and insignificant in the third model. The industry value added has a positive effect (as expected) and it is fully significant in the second model and insignificant in the third model. Finally, the agriculture value added variable has a negative effect but it is insignificant in the third model and a positive effect and it is statistically significant for 10% level in the last model formulation.

Our results indicate the existence of an inverted U-shaped relationship between economic development and pollution in the form of CO_2 as shown in Figure

2. The turning point occurs at $9930 when we look at the reduced form of the model formulation while it is quite lower when we consider the full model. Specifically in the full model the turning points range from $480 to $1276. This is an interesting empirical finding showing that in the case of the direct effect of growth on emissions the turning point is much higher while when we look at the full model with the influence of trade and the value added by the various sectors of the economy the turning points are much lower.

Moreover, table 3 provides us with a number of basic diagnostic tests for each model formulation. Specifically the tests refer to normality (Bera-Jarque), autocorrelation (Breusch-Godfrey), ARCH LM test and the Ramsey RESET test. In all cases of the full model formulations the diagnostic tests indicate no violation of the basic hypotheses of the regression analysis models while in the reduced form we have problems of normality at levels less than 10%, and of autocorrelation for levels less than 5%. The results of the RESET tests indicate that the equations of our model are in all cases correctly specified.

Finally, Figure 2 presents the inverted U-shaped curve and the associated turning point in the case of the full model with all explanatory variables considered simultaneously.

Table 3: Regression results adjusted for serial correlation (NLS)

	Model			
	Reduced	Full		
Constant	-5.5778 (-3.6313) [0.0008]	-7.097 (-7.734) [0.0000]	-7.5755 (-1.79377) [0.0813]	-1.7885 (-1.347) [0.1862]
Log GDPc	1.5664 (2.986) [0.0048]	0.6954 (1.9582) [0.0588]	0.50177 (0.95445) [0.3462]	1.031 (2.8454) [0.0072]
Log $GDPc^2$	-0.0851 (-1.9385) [0.0595]	-0.054 (-2.051) [0.0472]	-0.03508 (-0.788) [0.4358]	-0.08351 (-2.9041) [0.0062]
Log Exports		0.226 (5.0415) [0.0000]	0.24233 (5.16) [0.0000]	0.24273 (5.20655) [0.0000]
Log AgrVA			0.1663 (0.3859) [0.7018]	-0.39823 (-2.4223) [0.0204]
Log SerVA			-0.01955 (-0.04496) [0.9644]	-0.59313 (-3.52013) [0.0000]
Log IndVA		0.8282 (3.8756) [0.0004]	0.91299 (1.4337) [0.1603]	
R^2	0.984	0.992	0.992	0.992
DW	1.7944	2.093	2.18	2.117
Bera-Jarque	5.3273 [0.0697]	0.2023 [0.9038]	0.1916 [0.9086]	2.006 [0.3669]
Breusch-Godfrey	6.5495 [0.0378]	1.4736 [0.2426]	3.3918 [0.1834]	1.3564 [0.5075]
ARCH LM	0.01925 [0.8896]	0.593 [0.4457]	1.4945 [0.2215]	0.3268 [0.5676]
RESET 1	0.4886 [0.6278]	1,1884 [0.2827]	1.2454 [0.2213]	0.13975 [0.8896]
RESET 2	1.2474 [0.2985]	1.0338 [0.3660]	1.602 [0.2163]	0.54685 0.5836]
Turning Points	9930	627	1276	480

t-statistics in parentheses; P-values in brackets

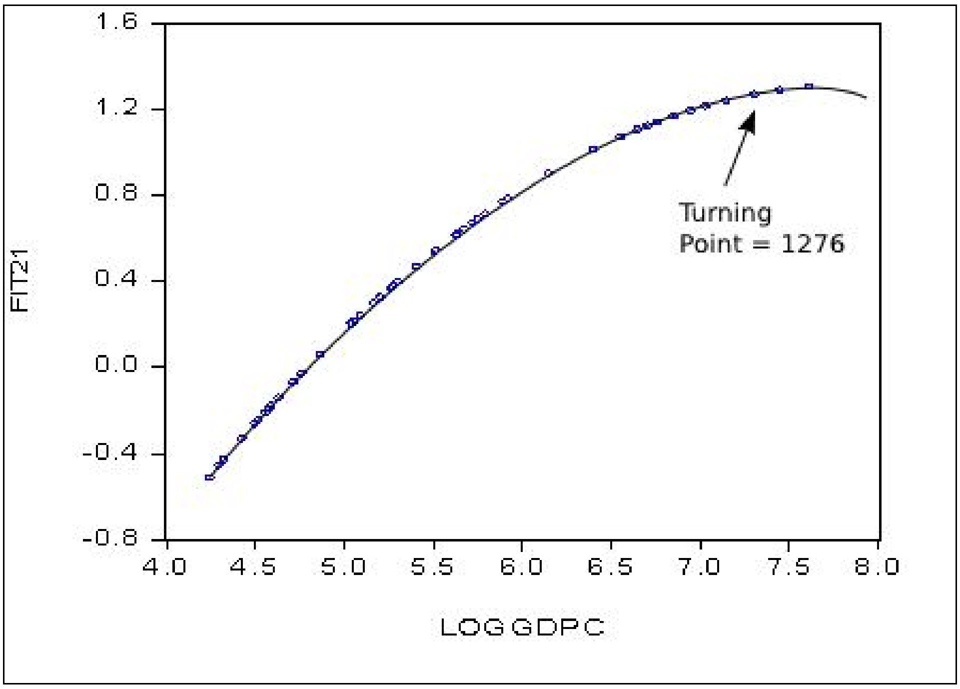

Figure 2: Estimated EKC in the full model

4. Conclusions and policy implications

Like inequality, pollution tends to become worse before it becomes better along China's development path. China, as a developing country, is currently the world's second largest carbon emitter after the USA and has been under a continuous international pressure for taking actions for this issue. The reduction of emissions is significant in both political and global grounds. Empirical studies have shown that various socioeconomic, legislative and technological factors may be used as tools for reducing China's energy-related CO_2 emissions (Ma and Stern, 2007).

The acceptance of an EKC hypothesis means that there is an inevitable level of environmental damage that follows up China's development at the earlier stage but with a significant improvement at a later stage of its economic growth. Thus, an EKC is the result of structural change that follows economic growth, but this may not be optimal if environmental critical loads are crossed irreversibly. The positively sloped part of an EKC where growth is worse may take a long time to cross. This implies a present value of higher future growth and cleaner future environment may be offset by high current rates of environmental damage. At the same time it may be cheaper to abate today than in the future (Panayotou, 1997).

Our empirical findings show the existence of an inverted U-shaped relationship between economic growth and CO2 emissions. Turning points occur at $9930 in the case of the reduced form while they are much lower in the full model ranging from $480 to $1276. This shows that when considering the direct effect of growth on emissions turning points are a lot higher compared to the indirect consideration with the effect of trade openness and contribution of the main sectors of the Chinese economy.

Trade seems to be an influential variable which requires specific attention. Zhao and Wang (2009) showed that market liberalization alone is not enough, and economic system reform and liberalization may be considered as complements. Additionally, efforts with the use of special economic zones (SEZs) and ways to attract foreign direct investment (FDI), are necessary for industrial improvement and export competitiveness (Hong and Anthony, 2007; Hong, 2007).

Acceptance of an EKC may seem as a temporary phenomenon and we may seek ways to stimulate growth like trade liberalization, price reform, economic restructuring, etc. Under trade openness, developed countries will loose their competitive advantage in polluting sectors over developing countries because the former have more stringent environmental policies. Eventually, trade openness will result in the development of pollution-intensive industries and environmental degradation in developing countries, while in developed countries environmental quality will increase (He, 2010).

Some of the steepness of an inverted U-shaped relationship between environmental damage in the form of pollution and economic growth is caused by various policy distortions such as protection of industry, energy subsidies, etc. Developing countries can flatten out their EKCs by defining and applying property rights over natural resources, eliminating any policy distortions and internalising environmental costs to the sources that generate them (Panayotou, 1993). Additionally, the improper allocation of property rights may result to market failure.

Ma and Stern (2007) claim that it is usually unacceptable to limit carbon emissions through scale effects and the control of population growth by limiting the continuously increasing per capita demand for commodities, and especially material needs and energy. This implies the alteration of technological and structural effects. Carbon emissions may be decreased by reducing the total energy intensity of the economy, by energy efficiency improvements in the production and consumption of commodities. This may be justified as the technological effect. Carbon emissions can be cost-effectively reduced by reducing the proportion of coal in total energy consumption by switching from coal to carbon-free energy alternatives (nuclear, wind, solar) or substituting with other fossil fuels like oil and natural gas. Huang et al. (2008) extract with their simulation results the effect on prices of the planned coal to liquids activities for China.

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