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Abstract

The paper investigates China's environmental performance-economic development relationship for the time period of 1965-2009. The results indicate that after 1990 China increased its environmental performance mainly driven by the implementation of several environmental policies. In addition when we taking into account several factors contributed to China's economic growth, the empirical evidences suggest the existence of an inverted "U" shape relationship between China's environmental performance and economic development. However, when only the influence of the industrial sector is taken into account the shape of the established relationship changes from an inverted "U" to "N" shape, indicating that the main determinant of China's environmental inefficiencies over the years was the heavily industrialization.

Keywords: Environmental performance; Environmental Kuznets Curve; China; Economic Growth.

JEL Classification: C01; C14, O15; Q5.

1. Introduction

The relationship between economic growth and environmental quality has been examined over the years. In a country level, Grossman and Krueger (1995) found a U-type (Environmental Kuznets Curve -EKC)[1] relationship between economic activity and environmental quality. So far this finding has been supported by several country level studies (among others Selden & Song, 1994; Ekins, 1997; Stern, 1998, 2002, 2004; Ansuategi & Perrings, 2000; Cavlovic, Baker, Berrens & Gawande, 2000; Andreoni & Levinson, 2001; Antweiler, Copeland & Taylor, 2001; Bulte & Soest, 2001; Dasgupta, Laplante, Wang & Wheeler, 2002; Halkos, 2003).

China's rapid economic growth over the last thirty years has been driven mainly by the highly rhythms of industrialization which in turn have increased welfare and living standards but with great environmental cost. Song, Zheng and Tong (2008) assert that the understanding of EKC relationship for China is of great interest. Several studies have explored the relationship of China's environmental pollution –economic growth relationship[2]. Depending on which pollutant is used and how it is measured, different EKC studies generate different results (Brajer, Mead and Xiao, 2011).

However, Wei, Ni and Du (2011) suggest that in the case of China the reduction of carbon dioxide emissions (CO_2) is the biggest task for policy makers. Shen (2006) using a two stage least squares (2SLS) model found that pollution and economic growth in China are jointly determined. Similarly Yaguchi, Sonobi and Otsuka (2007) in a comparative study between Japan and China found evidence supporting the EKC hypothesis. As they indicate, there are evidences that China is on the rising portion of the EKC curve. More recently, He (2008) using panel regional

[1] Kuznets (1955) showed that during the various economic development stages, income disparities first rise and then begin to fall.
[2] For a literature review of EKC studies for China see Brajer, Mead, and Xiao (2011).

data for 29 Chinese provinces for the time period of 1992-2003 found evidence of quadratic and cubic relationship between SO_2 emissions and income.

In addition, Song, Zheng and Tong (2008) using panel data models on waste gas emissions for the time period 1985 to 2005 found support of the EKC hypothesis. Similar results have been also reported from Diao, Zeng, Tam, and Tam (2009) for the Zhejiang area of China for the time period of 1995-2005. Furthermore, Brajer, Mead and Xiao (2011) by developing three air pollution measures for Chinese cities tried to establish the existence of an EKC relationship. At the same time they have found that the income-pollution relationship differs by pollutant with some pollutants having periods of decline while others may be continuously increasing. Finally, Halkos and Tzeremes (2011) provided evidence that indicate the presence of an inverted U-shaped curve between CO_2 emissions and economic growth represented by the GDP per capita.

However in contrast to the majority of China's EKC studies, our study measures the tradeoff between China's environmental quality and economic growth in the modeling principles of Färe, Grosskopf, Lovell and Pasurka (1989) with the application of distance functions in a nonparametric setting. The study by Färe, Grosskopf, Lovell and Pasurka (1989) was the first to model environmental technology in a production function framework by treating pollutant as an output (bad output) of the production process and by imposing strong and weak disposability of the outputs used. As a result of this approach environmental performance indicators (hereafter EPIs) can be developed modeling the tradeoff between economic growth and pollution in a single index. Later, Tyteca (1997) introduced another EPI based on the same principles as Färe, Grosskopf, Lovell and Pasurka (1989) but with different assumptions.

Furthermore, Chung, Färe and Grosskopf (1997) using the weak disposability assumption of outputs constructed a Malmquist–Luenberger index, creating for the first time environmental productivity indexes. Following the modeling principle by Färe, Grosskopf, Lovell and Pasurka (1989), several other country level studies have examined the relationship between economic growth and environmental performance trying to establish the existence of the EKC relationship (Zaim & Taskin, 2000; Taskin & Zaim, 2001; Zofio & Prieto, 2001; Zaim, 2004; Managi, 2006; Yörük & Zaim, 2006; Picazo-Tadeo & García-Reche, 2007; Halkos and Tzeremes, 2009).

In that respect, our study for the first time (to our knowledge) constructs an environmental performance index in CO_2 emissions for China covering a period of forty five years. In addition we test for the existence of the EKC hypothesis by including several other factors that contributed to China's economic reform over the examined period.

2. Data and Methodology

2.1 Description of Variables

A number of variables for the period 1965-2009 were considered in our analysis. Based on several studies similar to ours (Färe, Grosskopf, Lovell & Pasurka, 1989; Färe, Grosskopf & Tyteca, 1996; Chung, Färe & Grosskopf 1997; Tyteca, 1996, 1997; Taskin & Zaim, 2001; Zofio & Prieto, 2001; Zaim, 2004) the environmental production function includes two inputs: capital stock and total labour force. As in several studies we use the following perpetual inventory method (Verstraete, 1976; Epstein & Denny, 1980; Nadiri & Prucha, 1996; Terregrossa, 1997; Wei, Ni & Du, 2011) as: $K_t = I_t + (1-\delta)K_{t-1}$, where K_t and K_{t-1} are the gross capital stock in the current and in the previous year respectively and δ represents the depreciation rate of capital stock[3].

In addition the environmental production function uses two outputs: GDP (in constant 2000 US$ -good output) and CO_2 emissions (in kt -bad output). That is, in our case, growth is accounted by the Gross Domestic Product per capita-GDPc. Several other variables have been used in order to test for a Kuznets-type relationship between China's environmental performance and several other factors. Specifically, we use the agriculture value added-AVA (% of GDP), the industry value added-IVA (% of GDP), the services value added-SVA (% of GDP) and China's trade volumes-TV (% of GDP)[4]. Table 1 provides the descriptive statistics of the variables used indicating the rapid development and changes over the years (looking at the standard deviations) of the Chinese economy.

***Table 1**: Descriptive statistics of the variables used*

	Capital Stock	***Labor force, total***	***GDP (constant 2000 US$)***
mean	14021053520713.10	585679200.75	700537133669.19
std	2367070730381.36	142438841.70	768289204453.76
min	12436857794362.80	352727000.00	71617200000.00
max	21786301038403.70	786411085.49	2940225014706.47
	CO2 emissions (kt)	***GDP per capita (constant 2000 US$)***	***Trade (% of GDP)***
mean	2272998.82	573.48	30.07
std	1562912.31	567.84	19.87
min	432880.00	92.57	3.19
max	6533018.00	2208.40	70.57
	Agriculture, value added (% of GDP)	***Services, value added (% of GDP)***	***Industry, value added (% of GDP)***
mean	25.40	30.60	44.01
std	9.27	7.20	3.92
min	10.33	21.60	31.18
max	42.15	43.43	48.22

3 Following several authors δ is assumed equal to 6% (Zhang, Cheng, Yuan & Gao, 2011).

4 The source of all these data is the Wold Bank database available at: http://data.worldbank.org/country/china

2.2 Computing China's Environmental Performance Index

One of the ways that the bad output can be modelled appeared in the pioneered work by Färe, Grosskopf, Lovell and Pasurka (1989) by assuming strong (for desirable outputs) and weak (for undesirable outputs) disposability treating environmental effects as undesirable outputs in a hyperbolic efficiency measure. Generally the property of weak disposability of detrimental variables is well known and has been used in several formulations (Färe, Grosskopf & Tyteca, 1996; Chung, Färe & Grosskopf, 1997; Tyteca, 1996, 1997; Zofio & Prieto, 2001). But, although this approach is widely accepted among the environmental economists it has faced several criticisms (Hailu & Veeman, 2001; Färe & Grosskopf, 2003; Hailu, 2003, Kuosmanen, 2005; Färe & Grosskopf, 2009; Kuosmanen & Podinovski, 2009).

At the same time several other studies have treated bad output as input when measuring environmental efficiency (Pitman, 1981; Cropper & Oates, 1992; Reinhard, Lovell & Thijssen, 2000; Dyckhoff & Allen, 2001; Hailu & Veeman, 2001; Korhonen & Luptacik, 2004; Mandal & Madheswaran, 2010). Our study in order to measure China's environmental performance uses the weak disposability assumption in a directional distance function measure.

Therefore, following the notation by Färe and Grosskopf (2004) we let $P(x)$ to denote an input vector $x \in \Re_{+}^{N}$ which can produce a set of undesirable $u \in \Re_{+}^{K}$ and desirable $y \in \Re_{+}^{M}$ outputs. Then in order to determine the environmental technology several assumptions are needed to be taken following Shephard (1970), Shephard and Färe (1974) and Färe and Primont (1995). We assume that the output sets are closed and bounded and that inputs are freely disposal. In addition $P(x)$ can be an environmental output set if:

1. $(y,u) \in P(x)$ and $0 \le \theta \le 1$ then $(\theta y, \theta u) \in P(x)$ (i.e. the outputs are weakly disposable) and

2. $(y,u) \in P(x)$, $u = 0$ implies that $y = 0$ (i.e. the null jointness assumption of good and bad outputs).

The weak disposability assumption implies that the reduction of bad outputs is costly and therefore the reduction of bad outputs can be obtained only by a simultaneous reduction of good outputs. In addition the assumption which indicates that the good outputs are null-joint with bad outputs implies that the bad outputs are byproducts of the production process when producing good outputs. In order to formalize the environmental technology we use data envelopment analysis (DEA) framework.

If we let $k = 1,...,K$ be the observations then the environmental output can be formalized as:

$$\begin{aligned} P(x) = \Big\{ (y,u) : & \sum_{k=1}^{K} z_k y_{km} \ge y_m, m = 1,...,M, \\ & \sum_{k=1}^{K} z_k u_{kj} = u_j, j = 1,...,J, \\ & \sum_{k=1}^{K} z_k x_{kn} \le x_n, n = 1,...,N, \\ & z_k \ge 0, k = 1,...,K \Big\} \end{aligned} \tag{1}$$

$z_k, k = 1,...,K$ indicate the intensity variables which are not negative and imply constant return to scale[5]. The inequality on the good outputs and the equality on the bad outputs help us to impose the weak disposability assumption and only strong

[5] China's environmental performance levels (efficiencies) in our study are computed by regarding the different years/ time periods as different decision making units (DMUs). Thus it is assumed that there are not any variable returns to scale (since we are comparing China with itself in different chronicle stages). However, if the variable returns are needed to be calculated the $\sum_{k=1}^{K} z_k = 1$ restriction must be added to the linear programming problem (1).

disposability of good outputs. However the null-jointness is imposed by the following restrictions on bad outputs:

$$\begin{aligned} &\sum\nolimits_{k=1}^{K} u_{kj} > 0, j = 1,...,J, \\ &\sum\nolimits_{j=1}^{J} u_{kj} > 0, k = 1,...,K. \end{aligned} \qquad (2).$$

Furthermore, we apply the directional distance function approach as in Chung, Färe & Grosskopf (1997) and in order to be able to reduce bad and expand good outputs. In order to be able to model that in the directional distance function setting we use a direction vector $g = (g_y, -g_u)$, where $g_y = 1$ and $-g_u = -1$. Then the efficiency score for DMU k' (as mentioned before we treat each year as a different DMU) can be obtained from:

$$\begin{aligned} &\vec{D}_o\left(x^{k'}, y^{k'}, u^{k'}; g\right) = \max \beta \\ &s.t. \left(y^{k'} + \beta g_y, u^{k'} - \beta g_u\right) \in P(x) \end{aligned} \qquad (3).$$

Next the linear programming problem can be calculated as:

$$\begin{aligned} &\vec{D}_o\left(x^{k'}, y^{k'}, u^{k'}; g\right) = \max \beta \\ &s.t. \quad \sum_{k=1}^{K} z_k y_{km} \geq y_{k'm} + \beta g_{ym}, m = 1,...,M, \\ &\qquad \sum_{k=1}^{K} z_k u_{kj} = u_{k'j} - \beta g_{uj}, j = 1,...,J, \\ &\qquad \sum_{k=1}^{K} z_k x_{kn} \leq x_{k'n} \\ &\qquad z_k \geq 0, k = 1,...,K. \end{aligned} \qquad (4).$$

Efficiency is then denoted when $\vec{D}_o\left(x^{k'}, y^{k'}, u^{k'}; g\right) = 0$ and inefficiency by $\vec{D}_o\left(x^{k'}, y^{k'}, u^{k'}; g\right) > 0$. Due to the fact that we are using the efficiency scores obtained in a second stage analysis we present the efficiency scores obtained in terms of Shephard's output distance function. In fact according to Chung, Färe & Grosskopf

(1997) Shephard's output distance function is a special case of the directional distance function and can be calculated as:

$$D_o(x,y,u)=1/\left(1+\vec{D}_o\left(x^k,y^k,u^k;y^k,u^k\right)\right) \quad (5).$$

Figure 1 illustrates the directional distance function for a case of one undesirable output and one desirable output for China's environmental output set $P(x)$. The "null jointness" property described in (2) is diagrammatically represented because the function passes through the origin. The distance between a point (y,u) and the frontier $(y+\beta g_y, b-\beta g_u)$ is represented by the value of β. The direction vector $g=(g_y,-g_u)$ indicates the direction in which the environmental performance is measured with g_y indicating the direction of good output (in our case GDP) and with the direction vector g_u indicating the bad output (CO_2). Therefore given China's environmental production technology $(P(x))$ and the specified direction vector (g), the directional distance function yields the contraction of China's CO_2 emissions and the maximum feasible expansion of its GDP.

2.3 Econometric approach

The variables mentioned in the previous section are used in time series analysis model formulation. Table 2 presents the unit root tests for the variables considered. As can be realized all variables are I(1) in first differences and I(0) in levels. At the same time the result of the Engle-Granger cointegration test confirms co-integration among the variables as shown at the bottom of Table 2.

Figure 1: Graphical presentation of the directional output distance function

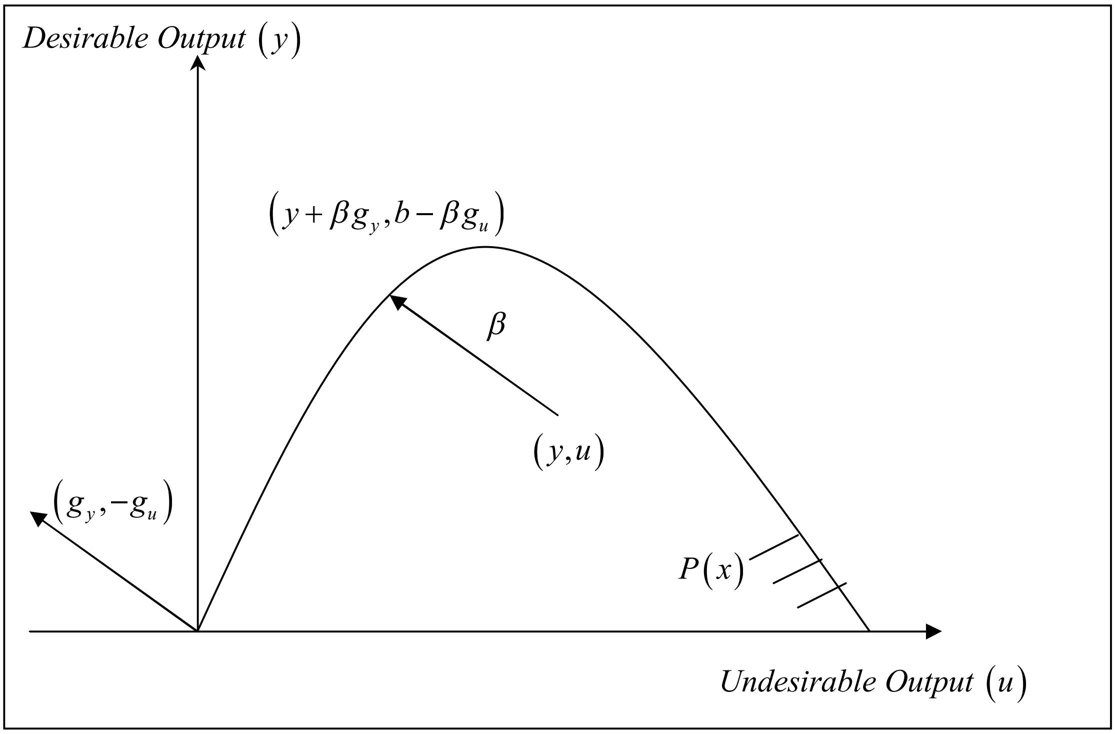


Table 2: Unit root Dickey-Fuller tests (with intercept)[6]

EPI	**GDPc**	**TV**	**SVA**
0.0602 [0.6967]	3.6145 [1.0000]	1,56112 [1.000]	-0.5586 [0.8691]
Δ(EPI)	**ΔGDPc**	**Δ(TV)**	**Δ(SVA)**
-4.8239 [0.0000]	-5.1398 [0.0000]	-6.7788 [0.0000]	-5.0962 [0.0001]
AVA	**IVA**	**Engle-Granger**	
-0.26201 [0.9222]	-2.1284 [0.2350]	-6.0864 [0.0000]	
Δ(AVA)	**Δ(IVA)**		
-5.702 [0.0000]	-5.4443 [0.0000]		

As we are interested in the terms of the main effects we have not included interactions. The full form of the proposed model with the inclusion of the statistically important variables takes the form:

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

$$EPI_t = a_0 + a_1\, GDPc + a_2\, GDPc^2 + a_3\, GDPc^3 + a_4\ TV +$$

$$+ a_5\, AVA + a_6\, IVA + a_7\, SVA + \lambda\ EPI_{t-1} + \varepsilon_t \qquad (6)$$

where EPI is the dependent variable and GDPc, trade volume (TV), agriculture value added (AVA), industry value added (IVA) and services value added (SVA) the explanatory variables. ε_t is the error term. The inclusion of the lag dependent variable shows the effect of a change in EPI in the previous year on the current year as well as the speed in which this adjustment is achieved.

Specifically we assume a partial adjustment model which combines two parts, a static (describing how the desired level is determined) and a dynamic process in the form:

$$EPI_t - EPI_{t-1} = \lambda(EPI_t^* - EPI_{t-1}) \qquad (7)$$

Where EPI* is the desired level of EPI. Substituting the expression for EPI* into (6) we obtain:

$$EPI_t = \gamma_0\lambda + \lambda\gamma_1\, \beta_1\, GDPc + \lambda\gamma_2\, GDPc^2 + \lambda\gamma_3\, GDPc^3 + \lambda\gamma_4\, TV +$$

$$+ \lambda\gamma_5\, AVA + \lambda\gamma_6\, IVA + \lambda\gamma_7\, SVA + (1-\lambda)\ EPI_{t-1} + \varepsilon_t \qquad (8)$$

This equation can be estimated as a general ARDL model as follows:

$$EPI_t = \beta_0 + \beta_1\, GDPc + \beta_2\, GDPc^2 + \beta_3\, GDPc^3 + \beta_4\ TV +$$

$$+ \beta_5\, AVA + \beta_6\, IVA + \beta_7\, SVA + \beta_8\ EPI_{t-1} + \beta_9\, GDPc_{t-1} + u_t \qquad (9)$$

In our case the restriction $\beta_9=0$ was imposed. The estimated adjustment parameter λ measures the speed with which adjustment is achieved and lies between 0 and 1.

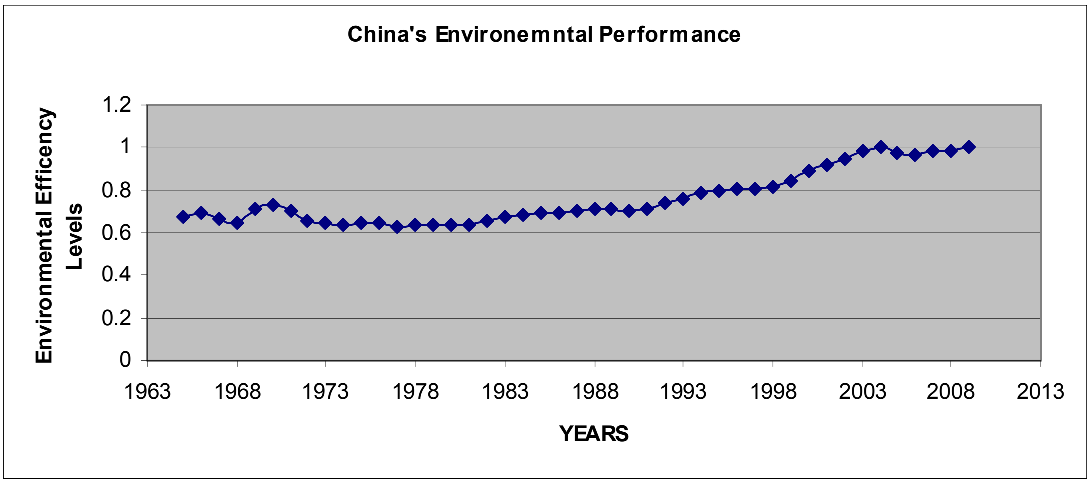
3. Empirical Results

The results of China's environmental performance levels over the years are presented in Figure 2. It appears that after the year 1990 China's environmental performance levels started to increase. This result fully supports the studies by Kim

(2001), Lu (2005) and Schreus (2008) who noted that after 1989 China has several attempts through the annual environmental reports and the introduction of new environmental laws in order to reduce environmental pollution.

Furthermore, Qu, Kuyvenhoven, Shi and Heerink (2010) emphasise the fact that China's 11th Five-Year Plan covering the period 2006–2010 has focused on two main targets: first on the application of a framework of economic development with emphasis on environmental protection and secondly on the use of administrative methods which can address environmental problems. As can be realised from our results presented in Figure 2 China's environmental policy orientation has started to have an effect on its environmental performance levels.

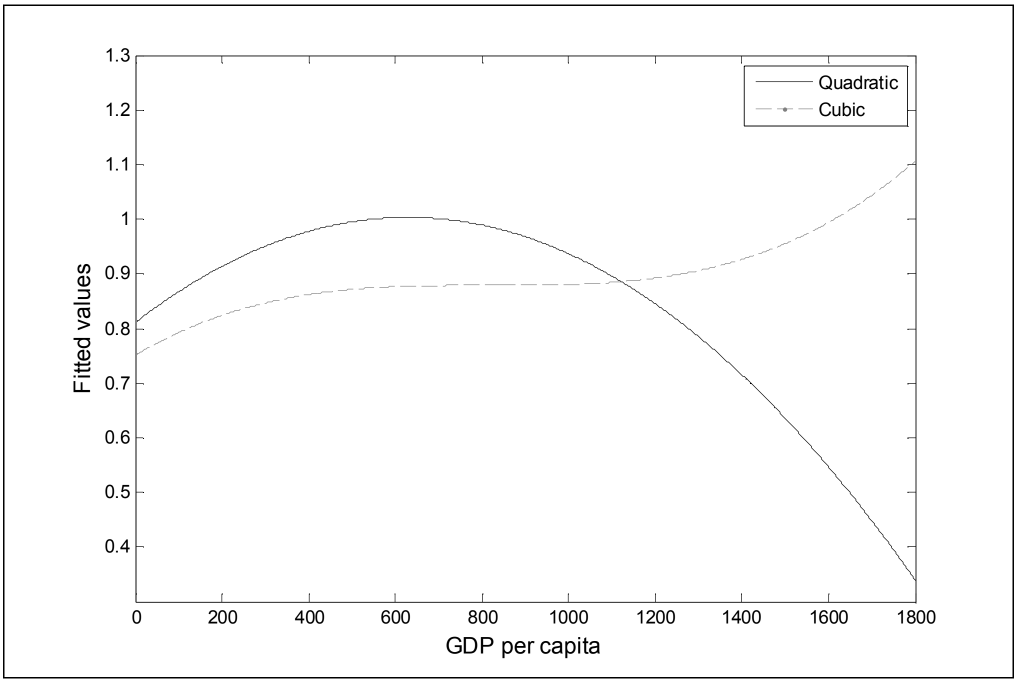
Figure 2: Environmental efficiency scores for the years 1965-2009



In addition table 3 presents the empirical results of the fitted models. Specifically, the first column presents the results of the static model (I) while the next two columns present the models' results (II - III) with the dependent variable lagged by one period. In all cases we have a very high level of predictability (from 87% to 93%). An inverted U-shaped curve is observed in the case of model I (without the lag of the dependent). If the latter is added in the model then the results show an inverted

U-shape between EPI and growth in model II with the contribution of all sectors included and a cubic relationship in the case of model III with only the industrial sector effect (Figure 3).

Figure 3: China's Environmental performance-GDPc relationship



The constant term, the GDPc and the GDPc squared are significant for all levels in models I and III and only at a level of 10% in model II. It is worth mentioning that trade seems to be statistically significant only in the static model and it has a positive effect. The cubic term of GDPc is significant in model III. In terms of the sector variables, we can see that the service and the agriculture value added variables have a negative influence (as expected) and they are significant in all levels in model I and for a level of 10% in model II. The industrial value added variable has a negative effect and it is statistically significant in models I and III for all statistical levels of significance and for a level of 10% in model II.

Our results indicate the existence of a "light" N-shape in the case of model III with turning point equal to $791 and $839. The fact that the turning points are so close to each other is probably due to the high industrialization rates that China has gone through and this implies instability in its environmental performance levels. In the static model I we find an inverted U-shaped relationship between economic development and environmental efficiency index with the turning point occurring at $631 while the turning point is higher ($743) when we consider the influence of all sectors in the dynamic formulation of model II. This is an interesting empirical finding which implies that the turning point is higher when we look at model II with the influence of the value added by the various sectors of the economy.

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. The results of the RESET tests indicate that the equation of model I is not correctly specified while the Bera-Jarque test indicates normality problem for model II. In the case of model III the diagnostic tests indicate no violation of the basic hypotheses of the regression analysis models.

Let us now discuss the speed with which environmental efficiency performance adjusts to its equilibrium value. This adjustment is slow. The lag coefficient in the estimated equation shows that the adjustment of EPI proceeds at a rate of around 41.5% per annum (1-0.5852). This implies that 41.5% of the discrepancy between the desired and the actual levels of environmental inefficiencies are eliminated in a year. We could say that the adjustment of environmental inefficiencies is fulfilled within almost two and a half time periods. The causes of this slow adjustment of EPI should be found mainly in the institutional characteristics of the industrial sector.

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

Variables	Model		
	I	II	III
Constant	40.9974 (3.5417) [0.0011]	15.4135 (2.42) [0.021]	0.635885 (3.42916) [0.0015]
GDPc	0.000613 (2.8209) [0.0076]	0.000385 (2.30) [0.027]	0.000474 (3.30264) [0.0021]
$GDPc^2$	-4.86E-07 (-3.3058) [0.0021]	-2.59E-07 (-2.45) [0.019]	-5.82E-07 (-2.80741) [0.0078]
$GDPc^3$			2.38E-10 (2.5563) [0.0147]
TV	6.38E-07 (2.3596) [0.0235]		
AVA	-0.3957 (-3.4306) [0.0015]	-0.1475 (-2.34) [0.025]	
SVA	-0.3936 (-3.3859) [0.0017]	-0.1487 (-2.32) [0.026]	
IVA	-0.4112 (-3.5413) [0.0011]	-0.1551 (-2.42) [0.021]	-0.00751 (-3.3418) [0.0019]
EPI_{t-1}		0.5984 (6.03) [0.0000]	0.5852 (4.9898) [0.0000]
R^2	0.87	0.93	0.93
Bera-Jarque	6.5775 [0.0373]	17,389 [0.0002]	3.6056 [0.1606]
Breusch-Godfrey	1.6468 [0.1994]	1.143 [0.5647]	1.2962 [0.5230]
ARCH LM	1.6468 [0.1994]	0.4152 [0.5115]	0.9993 [0.3175]
RESET	8.679 [0.0055]	1.8404 [0.1836]	1.2632 [0.2683]
Turning Points	$630.7	$743.24	$791.4 - $838.9

t-statistics in parentheses; P-values in brackets.

4. Conclusions

Our paper for the first time provides evidence of China's environmental performance-economic growth relationship taking into account several factors which has been contributed to China's enormous economic growth over the years. In addition it tried to investigate if on the mentioned relationship a Kuznets type relationship was existed. By applying several econometric (static and dynamic) models it appears when we take into account the effect of China's trade volumes, agricultural sector, services sector and industrial sector the relationship is quadratic which is indicated by an inverted "U" shape. But when applying only the effect of industrial sector it appears that the China's environmental performance – economic development relationship changes to cubic indicated by a light "N" shape[7]. The very close estimated turning points indicate instability in China's environmental performance levels due probably to the high industrialization rates that China has gone through during the period under consideration.

Finally, from our empirical results it can be observed that when taking into account, in a dynamic framework, the effect of trade, services and agriculture appear to have no effect on China's environmental inefficiency levels. However it is reported that the industrial sector is the main determinant of China's environmental inefficiencies, indicating that China's environmental policies must focus on different model of economic development than the one followed so far and was based on China's heavily industrialization.

[7] However it can be said that the inclusion of other explanatory variables in the model specification, can influence significantly the estimated relationship. Roca, Padilla, Farré and Galletto (2001) claim that estimated EKC is not as strong when more independent variables are used together with income.

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