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Abstract

By applying conditional and unconditional data envelopment analysis (DEA) models along side with statistical inference using bootstrap techniques; this paper investigates the link between China's carbon dioxide emissions (CO_2) environmental efficiency and its economic growth (measured in GNI per capita) for the time period of 1965 to 2009. The results reveal that China's changing consumption patterns has caused emissions levels to increase dramatically the last two decades providing clear evidence of a negative effect of China's GNI per capita increase on its environmental efficiency.

Keywords: Environmental efficiency; Economic growth; Carbon dioxide emissions;

China; Data envelopment analysis; Conditional efficiency, Bootstrap procedures

JEL Classification: C6, C23, O13, Q5

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1. Introduction

The relationship between economic growth and environmental quality has been a subject of investigation for several years. Kuznets (1955) showed that during the various economic development stages, income disparities first rise and then begins to fall. In these lines, some economists believe that there is an inverted U-shaped relationship between economic growth (in the form of per-capita income) and environmental degradation. Grossman and Kruger (1993, 1995) when investigating the relationship between economic activity and environmental quality they found an inverted U-type relationship (Environmental Kuznets Curve-EKC). Several authors have reached to the same conclusion (among others Selden and Song, 1994; Ekins, 1997; Stern, 1998, 2002, 2004; Ansuategi and Perrings, 2000; Cavlovic *et al.*, 2000; Andreoni and Levinson, 2001; Antweiler *et al.*, 2001; Bulte and Soest, 2001; Dasgupta *et al.*, 2002). According to Taskin and Zaim (2001) there is almost common agreement that a monotonic relationship between economic growth and carbon dioxide emissions exists, in contrast to the other pollutants which have an inverted U-shape relationship. However it must be noted that according to Andreoni and Levinson (2001) and inverted U-shape relationship exists because of increasing returns to scale (i.e. EKC hypothesis is based on scale economies).

Given the importance of carbon dioxide emissions (CO_2) and its effect on global warming (Holtz-Eakin and Selden, 1995), its relationship with countries' economic growth is of great interest among the environmental policy makers. According to Wei *et al.* (2011) the reduction of carbon dioxide emissions is the biggest task for policy makers especially for larger industrialised countries like China. Kim (2001) suggests that China is the largest air pollutant in Northeast Asia which affects climate change, stratospheric ozone depletion and acid deposition (acid rain).

According to Lu (2005) China’s economic growth in the recent history came with a high cost in terms of environmental deterioration and energy usage. In addition Schreurs (2008) suggests that after the end of the Cold War in 1989 China has made several attempts through the annual environmental reports and the introduction of new environmental laws in order to reduce environmental pollution and energy consumption. Several studies have tried to establish a U-shape relationship between economic growth and environmental pollution for the case of China. Deacon and Norman (2006) have found evidence for EKC hypothesis in per capita terms between income and SO2. Shen (2006) using a two stage lest square (2SLS) model found that pollution and economic growth in China are jointly determined. Similarly Yaguchi *et al.* (2007) in a comparative study between Japan and China have found evidence supporting EKC hypothesis, however as they indicate, there are evidences that China is on the rising portion of the EKC curve. More recently, He (2008) using panel regional data for 29 Chinese provinces for the time period of 1992-2003 have found evidence of quadratic and cubic relationship between SO2 emissions and income. Song *et al.* (2008) using panel cointegration modelling on waste gas emissions for the time period 1985 to 2005 have found evidences of the EKC hypothesis. Similar results have been also reported from Diao *et al.* (2009) for the Zhejiang area of China for the time period of 1995-2005. Furthermore, Brajer *et al.* (2011) by developing three air pollution measures for Chinese cities tried to establish the existence of an EKC relationship. However they have found that the income-pollution relationship differs by pollutant with some pollutants having periods of decline whiles others may be continuously increasing.

Our paper in order tries to establish the economic growth-air pollution relationship by constructing environmental performance/efficiency indicators (in an environmental technology context) and then examines whether these indicators are affected by China's economic growth levels. The main advantage of the construction of environmental efficiency indicators is that combines simultaneously in one metric economic growth and the different levels of pollutants in a environmental technology framework. The first model measuring environmental technology in production function framework was the one introduced by Färe *et al.* (1989). It was the first model based on the production theory constructing environmental performance indicators (EPIs). Later, Tyceta (1997) has introduced another EPI based on the same principles as Färe *et al.* (1989) but with different assumptions. The construction of EPIs has been introduced by several papers that incorporate them. Furthermore, Chung et al. (1997) by using the weak disposability assumption of outputs constructed a Malmquist–Luenberger index, constructing for the first time environmental productivity indexes. In addition, into their analysis (Zaim and Taskin, 2000; Taskin and Zaim, 2001; Zofio and Prieto, 2001; Zaim, 2004; Managi, 2006; Yörük and Zaim, 2006; Picazo-Tadeo and García-Reche, 2007, Halkos and Tzeremes, 2009a).

The majority of those studies have used a two-stage analysis in order to establish a link between economic growth and environmental performance. According to Simar and Wilson (2007, 2011) the studies using a second-stage regressions involving DEA efficiency scores are subject to inference problems and several restrictions due to numerous assumptions made (which in some cases must be considered carefully). In addition to those studies our study applies the methodology introduced by Daraio and Simar (2005, 2007a, 2007b) and the statistical inference framework from Simar and Wilson (1998, 2000a, 2000b) in order to investigate the environmental efficiency-economic growth relationship for the case of China. Finally, De Whitte and Marques (2007, p. 25) emphasis the fact that when integrating these two frameworks can help us to avoid main drawbacks of efficiency analysis and have some attractive features such as a) the absence of separability condition, b) avoiding the need of priory assumption on the functional form of the model and c) allowing the exploration of the effect of environmental variables.

2. Methods adopted and data description

2.1 Data

Following several studies measuring environmental performance/ efficiency (Färe *et al.*, 1989, 1996; Tyteca, 1996; Zaim and Taskin, 2000; Zofio and Prieto, 2001; Picazo-Tadeo and García-Reche, 2007) the inputs used here are total labour force (in thousands) and capital stock (at current prices in millions US dollars) whereas the output ('good' output) used is the Gross Domestic Product (GDP-constant 2000 US$).We also use one more variable (in the literature indicated previously is referred to as undesirable output) measured by carbon dioxide (CO_2) emissions (kt). Finally following several studies (Beckerman, 1992; Kellenberg, 2008; Tsuzuki, 2008; Djoundourian, 2011) we are using as a measure of economic growth Gross National Income (GNI) per capita (constant 2000 US$)[1].

In addition since capital stock for China is not available we calculated it following the perpetual inventory method (Feldstein and Foot, 1971; Verstraete, 1976; Epstein and Denny, 1980; Nadiri and Prucha, 1996; Terregrossa, 1997) as $K_t = I_t + (1-\delta)K_{t-1}$, where K_t and K_{t-1} are the gross capital stock in current year

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[1] All the data have been subtracted from World Development Indicators database, World Bank, available at: http://databank.worldbank.org/ddp/home.do.

and in the previous year respectively and δ represents the depreciation rate of capital stock[2].

In addition many studies have used the undesirable output as input when measuring environmental efficiency (Pitman, 1981; Cropper and Oates, 1992; Reinhard *et al.*, 2000; Dyckhoff and Allen, 2001; Hailu and Veeman, 2001; Korhonen and Luptacik, 2004; Tsolas, 2005; Mandal and Madheswaran, 2010). Following those studies we apply a formulation where we treat undesirable output as input, due to the fact that both traditional inputs and undesirable output(s) impose costs to countries (Tsolas, 2011).

According to Mandal and Madheswaran (2010, p.1110) if the bad outputs are treated as inputs then they work as a proxy for the use of the environment in the form of its assimilative capacity. In fact the theory in Environmental Economics for treating pollution variable as input can be found in the formulation introduced by Brock (1973) who treated the flow of pollution as input in a production function. A similar production function was defined by Stockey (1996) treating the emission rates as inputs. According to Baumol and Oates (1988) and Fontein *et al.*, (1994) the inclusion of bad outputs with the fixed inputs in the production function has solid theoretical background in Environmental Economics.

2.2 DEA models and bias correction

As has been mentioned previously our study measures China's environmental efficiency levels for the time period of 1965-2009. Since we want to compare China's relative environmental efficiency levels for each year, we treat every year as a separate decision making unit (DMU). In that respect, following Koopmans (1951) and Debreau (1951) definition of production technology as a set of $x \in R_{+}^{p}$ inputs

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[2] Following several authors δ is equal to 6% (Wu, 2004; Zhang *et al.*, 2011).

which are used to produce $y \in R_{+}^{q}$ outputs. Then the feasible combinations of (x, y) can be defined as:

$$\Psi = \left\{ (x, y) \in R_{+}^{p+q} \middle| x \;\; can \;\; produce \;\; y \right\} \tag{1}$$

By assuming the assumption of free disposability of inputs and outputs then $(x, y) \in \Psi$, then $(x^{'}, y^{'}) \in \Psi$ when $x^{'} \geq x$ and $y^{'} \geq y$. In addition due to the fact that that input quantities appear to be the primary decision variables we use an input oriented models (Coelli *et al.*, 2005). As suggested by several authors (Førsund and Sarafoglou, 2002; Førsund and Sarafoglou, 2005; Førsund *et al.*, 2009), Hoffman's (1957) discussion regarding Farrell's (1957) paper was the first to indicate that linear programming can be used in order to find the frontier and estimate efficiency scores, but only for the single output case. Later, Boles (1967) developed the formal linear programming problem with multiple outputs identical to the constant returns to scale (CRS) model in Charnes *et al.* (1978) who named the technique as data envelopment analysis (DEA). Later, Banker *et al.* (1984) introduced a DEA estimator allowing for variable returns to scale (VRS model)[3].

As such, based on the Farrell (1957) measure for a unit operating at the level (x, y) the input oriented efficiency score can be defined as:

$$\theta(x, y) = \inf \left\{ \theta \middle| (\theta x, y) \in \Psi \right\} \tag{2}$$

Then the efficiency measurement of a given country (x_i, y_i) defines an individual production possibilities set $\psi(x_i, y_i)$ which under the assumption of free disposability of inputs and output can be expressed as:

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[3] For further analysis, variations and several applications of DEA models see also Halkos and Tzeremes (2007, 2008, 2009b, 2010).

$$\psi(x_i, y_i) = \left\{ (x, y) \in \Re_+^{p+q} \middle| x \geq x_i, y \leq y_i \right\} \tag{3}$$

As such the union of these individual production possibilities sets provides the Free Disposal Hull (FDH) estimator (introduced by Derpins *et al.*, 1984) of the production set Ψ which can be written as:

$$\begin{aligned} \hat{\Psi}_{FDH} &= \bigcup_{i=1}^{n} \psi(x_i, y_i) \\ &= \left\{ (x, y) \in \Re_+^{p+q} \middle| x \geq x_i, y \leq y_i, i = 1, \ldots, n \right\} \end{aligned} \tag{4}$$

Then the DEA estimator[4] $\hat{\Psi}_{DEA}$ is obtained by the convex hull (CH) of $\hat{\Psi}_{FDH}$ and can be calculated as:

$$\begin{aligned} \hat{\Psi}_{DEA} &= CH\left(\bigcup_{i=1}^{n} \psi(x_i, y_i) \right) \\ &= \left\{ \begin{array}{l} (x, y) \in \Re_+^{p+q} \middle| y \leq \sum_{i=1}^{n} \gamma_i y_i ; x \geq \sum_{i=1}^{n} \gamma_i x_i \\ for(\gamma_1, \ldots, \gamma_n) \quad s.t. \gamma_i \geq 0, i = 1, \ldots, n \end{array} \right\} \end{aligned} \tag{5}$$

Then in order to obtain the corresponding input oriented DEA estimators of efficiency scores we need to plug in $\hat{\Psi}_{DEA}$ in equation (2). In addition by applying the methodology introduced by Simar and Wilson (1998, 2000a, 2000b) we perform the bootstrap procedure for DEA estimators in order to obtain biased corrected results. More analytically the biased corrected estimations can be obtained from:

$$\begin{aligned} \hat{\hat{\theta}}_{DEA}(x, y) &= \hat{\theta}_{DEA}(x, y) - \widehat{bias}_B\left(\hat{\theta}_{DEA}(x, y) \right) \\ &= 2\hat{\theta}_{DEA}(x, y) - B^{-1} \sum_{b=1}^{B} \hat{\theta}^*_{DEA,b}(x, y) \end{aligned} \tag{6}$$

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[4] We consider here only the CRS case; however VRS estimation can be obtained by adding the constrain $\sum_{i=1}^{n} \gamma_i = 1; \gamma_i \geq 0,$ in equation (5).

Furthermore, by expressing the input oriented efficiency in terms of the Shephard (1970) input distance function as $\hat{\delta}_{DEA}(x,y) \equiv \frac{1}{\hat{\theta}_{DEA}(x,y)}$ we can constructed bootstrap confidence intervals for $\hat{\delta}_{DEA}(x,y)$ as:

$$\left[\hat{\delta}_{DEA}(x,y) - \hat{\alpha}_{1-a/2}, \hat{\delta}_{DEA}(x,y) - \hat{\alpha}_{a/2}\right] \quad (7).$$

2.3 Modelling the effect of GNI per capita on China's environmental efficiency levels

Daraio and Simar (2005, 2007a, 2007b) by extending the ideas developed by Cazals *et al.* (2002) developed a probabilistic formulation of the production process. This probabilistic approach allowed the introduction of external-environmental factors (Z) directly in the production process[5]. In contrast to the problems arising from the traditional two-stage approaches, the probabilistic approach introduced by Daraio and Simar (2005, 2007b) does not impose a separability assumption between Z values and the input-output space (De White and Verschelde, 2010)[6]. By denoting $Z \in \Re^r$ the external factors the joint distribution of (X,Y) conditional on $Z = z$ defines the production process if $Z = z$. Then the attainable production set Ψ^z is defined by:

$$H_{X,Y|Z}\left(x,y|z\right) = \text{Prob}\left(X \le x, Y \ge y|Z = z\right) \quad (8).$$

Then the input oriented conditional efficiency measure can be defined as:

$$H_{X,Y|Z}\left(x,y|z\right) = \text{F}_{X,Y|Z}\left(x,y|z\right) S_{Y|Z}\left(y|z\right) \quad (9).$$

In addition the input oriented efficiency score can be obtained from:

$$\theta(x,y|z) = \inf\left\{\theta|F_X\left(\theta x|y,z\right) > 0\right\} \quad (10).$$

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[5] For the theoretical background of the statistical properties of the conditional estimators see Jeong et al. (2010).

[6] According to Simar and Wilson (2007, 2011) the validity of the results obtained in a second stage analysis (explanatory analysis) when traditional methods like tobit and ordinary least squares is used are questionable due to the absence of valid inference and of several unsupported assumptions.

A kernel estimator can then be calculated as follows:

$$\hat{F}_{X|Y,Z,n}(x|y,z) = \frac{\sum_{i=1}^{n} I(x_i \leq x, y_i \geq y) K((z - z_i)/h)}{\sum_{i=1}^{n} I(y_i \geq y) K((z - z_i)/h)} \tag{11}$$

where K(.) is the Epanechnikov kernel[7] and h is the bandwidth of appropriate size. Following, Bădin *et al.* (2010) we use a fully automatic data-driven approach for bandwidth selection based on the work of Hall *et al.* (2004) and Li and Racine (2004, 2007) least-squares cross-validation criterion (LSCV) which leads to bandwidths of optimal size for the relevant components of Z. This method is based on the principle of selecting a bandwidth that minimizes the integrated squared error of the resulting estimate[8]. Li and Racine (2007) suggest that we have also to correct the resulting h by an appropriate scaling factor, which is $n^{-\frac{q}{(4+q+r)(4+r)}}$ where q is the dimension of Y and r is the dimension of Z [9]. Therefore, we can obtain a conditional DEA efficiency measurement defined as:

$$\hat{\theta}_{DEA}(x, y|z) = \inf\left\{\theta \middle| \hat{F}_{X|Y,Z,n}(\theta x|y,z) > 0\right\} \tag{12}.$$

Then in order to visualise the influence of an environmental variable on the efficiency scores obtained, a scatter of the ratios $Q_z = \hat{\theta}_n(x, y|z) - \hat{\theta}_n(x, y)$ against z (GNI per capita-GNIPC) and its' smoothed non parametric regression lines it would help us to analyse the effect of Z on the environmental efficiency scores obtained. For this purpose we use the nonparametric regression estimator introduced by Nadaraya (1965) and Watson (1964) as:

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[7] Other kernels from the family of continuous kernels with compact support can also be used.

[8] See Bădin et al. (2010) for a Matlab routine that computes the bandwidth based on the LSCV criterion.

[9] For more information regarding LSCV criterion and its properties see Silverman (1986), Hall et al. (2004) and Li and Racine (2004, 2007).

$$\hat{g}(z) = \frac{\sum_{i=1}^{n} K(\frac{z - Z_i}{h}) Q_z}{\sum_{i=1}^{n} K(\frac{z - Z_i}{h})} \qquad (13).$$

Finally, if this regression is decreasing it indicates that Z is unfavourable to China's environmental efficiency whereas if it is increasing then it is favourable. When Z is unfavourable then GNIPC acts like an extra undesired output to be produced demanding the use of more inputs in the production activity. In the opposite case China's GNIPC plays a role of a substitutive input in the environmental production process giving the opportunity to save inputs in the activity of production.

3. Empirical results

After performing the bootstrap procedure introduced by Simar and Wilson (1998, 2000a, 2000b), China's biased corrected environmental efficiency scores have been calculated along side with bootstrap 95% confidence intervals (table 1). In addition after performing the approach by Daraio and Simar (2005, 2007a, 2007b) along side with Simar and Wilson's inference procedure we calculated the biased corrected conditional environmental efficiency scores for the same time period, taking into account the effect of GNIPC (table 2). The results reveal that China's environmental efficiencies have been increased throughout the years regardless the effect of GNI. In addition when looking the descriptive statistics we realize that the mean value of the unconditional estimates is 0.5213 and for the conditional environmental efficiencies is 0.5207. This indicates that regardless the small difference between the unconditional and the conditional measures, China's environmental efficiency scores are similar. Almost identical results are reported and for the unconditional and conditional biased corrected environmental efficiency scores.

Table 1: Original environmental efficiency scores under the CRS assumption

YEARS	CRS	BCCRS	BIAS	STD	LB	UB
1965	0.3533	0.3393	-0.1166	0.0100	0.3116	0.3528
1966	0.3908	0.3754	-0.1053	0.0082	0.3448	0.3903
1967	0.3383	0.3248	-0.1227	0.0110	0.2983	0.3379
1968	0.2954	0.2835	-0.1422	0.0145	0.2604	0.2950
1969	0.4167	0.4003	-0.0984	0.0072	0.3675	0.4161
1970	0.4597	0.4415	-0.0897	0.0059	0.4054	0.4591
1971	0.3996	0.3832	-0.1066	0.0080	0.3520	0.3990
1972	0.3103	0.2970	-0.1440	0.0141	0.2727	0.3098
1973	0.2947	0.2818	-0.1550	0.0163	0.2582	0.2942
1974	0.2837	0.2711	-0.1628	0.0179	0.2482	0.2832
1975	0.2966	0.2834	-0.1571	0.0166	0.2593	0.2961
1976	0.2861	0.2733	-0.1637	0.0180	0.2497	0.2856
1977	0.2655	0.2531	-0.1837	0.0223	0.2300	0.2650
1978	0.2840	0.2706	-0.1740	0.0199	0.2457	0.2834
1979	0.2790	0.2655	-0.1823	0.0217	0.2410	0.2784
1980	0.2695	0.2555	-0.2029	0.0258	0.2315	0.2687
1981	0.2773	0.2629	-0.1972	0.0244	0.2382	0.2765
1982	0.3083	0.2926	-0.1734	0.0192	0.2654	0.3075
1983	0.3456	0.3282	-0.1528	0.0151	0.2977	0.3447
1984	0.3656	0.3465	-0.1513	0.0142	0.3138	0.3645
1985	0.3934	0.3722	-0.1451	0.0129	0.3370	0.3922
1986	0.3931	0.3709	-0.1529	0.0141	0.3341	0.3919
1987	0.4049	0.3809	-0.1557	0.0146	0.3415	0.4036
1988	0.4284	0.4022	-0.1520	0.0139	0.3589	0.4269
1989	0.4175	0.3908	-0.1635	0.0160	0.3480	0.4160
1990	0.4042	0.3771	-0.1779	0.0189	0.3332	0.4025
1991	0.4342	0.4048	-0.1675	0.0167	0.3576	0.4323
1992	0.4853	0.4519	-0.1524	0.0137	0.3988	0.4830
1993	0.5268	0.4888	-0.1475	0.0124	0.4297	0.5241
1994	0.5712	0.5283	-0.1420	0.0112	0.4636	0.5679
1995	0.5932	0.5453	-0.1481	0.0117	0.4745	0.5890
1996	0.6142	0.5600	-0.1575	0.0121	0.4856	0.6086
1997	0.6225	0.5594	-0.1812	0.0139	0.4796	0.6157
1998	0.6450	0.5755	-0.1872	0.0139	0.4935	0.6353
1999	0.6915	0.6198	-0.1673	0.0116	0.5318	0.6823
2000	0.7772	0.7063	-0.1291	0.0078	0.6107	0.7688
2001	0.8426	0.7692	-0.1132	0.0064	0.6670	0.8353
2002	0.8958	0.8163	-0.1087	0.0057	0.7080	0.8872
2003	0.9621	0.8747	-0.1039	0.0051	0.7583	0.9516
2004	1.0000	0.8981	-0.1134	0.0052	0.7760	0.9826
2005	0.9580	0.8288	-0.1627	0.0093	0.7062	0.9414
2006	0.9311	0.7739	-0.2181	0.0159	0.6500	0.9194
2007	0.9692	0.7841	-0.2435	0.0180	0.6567	0.9544
2008	0.9786	0.7708	-0.2755	0.0197	0.6478	0.9591
2009	1.0000	0.7685	-0.3012	0.0190	0.6501	0.9606
Mean	*0.5213*	*0.4722*	*-0.1589*	*0.0140*	*0.4153*	*0.5164*
Min	*0.2655*	*0.2531*	*-0.3012*	*0.0051*	*0.2300*	*0.2650*
Max	*1.0000*	*0.8981*	*-0.0897*	*0.0258*	*0.7760*	*0.9826*
Std	*0.2482*	*0.2011*	*0.0428*	*0.0052*	*0.1653*	*0.2420*

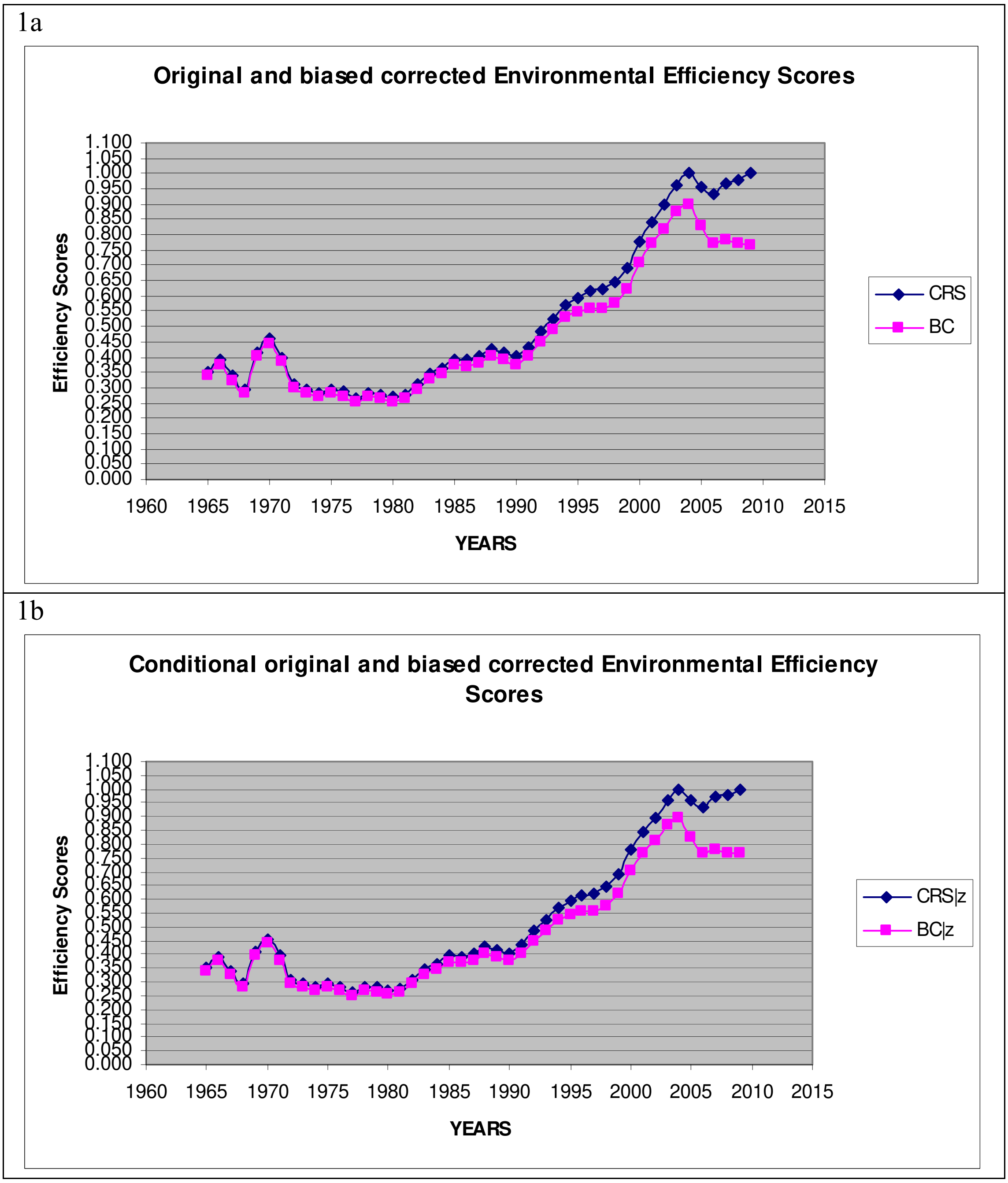
Table 2: Conditional to GNIPC environmental efficiency scores under the CRS assumption

YEARS	CRS|z	BC|z	BIAS	STD	LB	UB
1965	0.3529	0.3387	-0.1189	0.0100	0.3121	0.3524
1966	0.3901	0.3744	-0.1073	0.0082	0.3451	0.3896
1967	0.3381	0.3244	-0.1250	0.0109	0.2990	0.3377
1968	0.2950	0.2828	-0.1453	0.0144	0.2608	0.2946
1969	0.4104	0.3940	-0.1016	0.0074	0.3630	0.4100
1970	0.4568	0.4384	-0.0920	0.0060	0.4041	0.4563
1971	0.3966	0.3801	-0.1094	0.0081	0.3505	0.3961
1972	0.3085	0.2951	-0.1473	0.0141	0.2717	0.3081
1973	0.2944	0.2814	-0.1574	0.0160	0.2584	0.2940
1974	0.2836	0.2709	-0.1653	0.0176	0.2484	0.2832
1975	0.2965	0.2832	-0.1594	0.0163	0.2596	0.2961
1976	0.2833	0.2705	-0.1678	0.0180	0.2477	0.2829
1977	0.2637	0.2513	-0.1877	0.0219	0.2296	0.2633
1978	0.2804	0.2670	-0.1789	0.0198	0.2434	0.2799
1979	0.2783	0.2646	-0.1861	0.0212	0.2408	0.2779
1980	0.2690	0.2548	-0.2079	0.0254	0.2307	0.2684
1981	0.2769	0.2623	-0.2020	0.0240	0.2375	0.2763
1982	0.3082	0.2923	-0.1769	0.0189	0.2649	0.3076
1983	0.3455	0.3279	-0.1559	0.0148	0.2971	0.3449
1984	0.3656	0.3461	-0.1546	0.0141	0.3126	0.3648
1985	0.3934	0.3717	-0.1485	0.0128	0.3354	0.3925
1986	0.3931	0.3703	-0.1567	0.0141	0.3324	0.3921
1987	0.4049	0.3803	-0.1602	0.0147	0.3411	0.4038
1988	0.4270	0.4001	-0.1572	0.0141	0.3580	0.4257
1989	0.4155	0.3881	-0.1701	0.0164	0.3464	0.4140
1990	0.4030	0.3749	-0.1856	0.0195	0.3335	0.4015
1991	0.4342	0.4036	-0.1743	0.0171	0.3583	0.4326
1992	0.4853	0.4507	-0.1585	0.0141	0.3992	0.4835
1993	0.5268	0.4875	-0.1532	0.0129	0.4302	0.5246
1994	0.5712	0.5268	-0.1475	0.0116	0.4625	0.5686
1995	0.5932	0.5436	-0.1539	0.0122	0.4725	0.5897
1996	0.6142	0.5582	-0.1634	0.0127	0.4825	0.6084
1997	0.6225	0.5571	-0.1886	0.0146	0.4805	0.6137
1998	0.6450	0.5730	-0.1948	0.0146	0.4949	0.6346
1999	0.6915	0.6172	-0.1740	0.0121	0.5326	0.6807
2000	0.7772	0.7039	-0.1339	0.0082	0.6091	0.7683
2001	0.8426	0.7668	-0.1174	0.0067	0.6625	0.8353
2002	0.8958	0.8137	-0.1127	0.0061	0.7035	0.8870
2003	0.9621	0.8719	-0.1076	0.0053	0.7557	0.9518
2004	1.0000	0.8948	-0.1176	0.0054	0.7754	0.9814
2005	0.9580	0.8245	-0.1690	0.0097	0.7014	0.9394
2006	0.9311	0.7695	-0.2255	0.0166	0.6460	0.9158
2007	0.9692	0.7795	-0.2511	0.0187	0.6519	0.9512
2008	0.9786	0.7663	-0.2830	0.0205	0.6434	0.9578
2009	1.0000	0.7643	-0.3084	0.0198	0.6461	0.9578
Mean	*0.5207*	*0.4702*	*-0.1635*	*0.0142*	*0.4140*	*0.5155*
Min	*0.2637*	*0.2513*	*-0.3084*	*0.0053*	*0.2296*	*0.2633*
Max	*1.0000*	*0.8948*	*-0.0920*	*0.0254*	*0.7754*	*0.9814*
Std	*0.2486*	*0.2002*	*0.0440*	*0.0051*	*0.1643*	*0.2418*

In addition to tables 1 and 2, figure 1 illustrates the diachronically China's environmental efficiency scores, under the CRS hypothesis and for the time period of 1965-2009. As can be realized for the unconditional (subfigure 1a) and conditional (subfigure 1b) environmental efficiency scores the pattern is almost identical. It appears that after the year 1990 China's environmental efficiency scores started to increase dramatically. This result fully support the studies by Kim (2001), Lu (2005) and Schreus (2008) suggested 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. This increase is clearly indicated on figure 1 for the time period 1990 to 2003. However for the period 2003 to 2009 it appears to be a decrease both for unconditional and conditional environmental efficiency scores (looking the biased corrected efficiency scores BC, BC|z).

Similarly, figure 2 provides a graphical representation of the effect of GNIPC on China's environmental efficiency level. For this task we use the 'Nadaraya-Watson' estimator, which is the most popular method for nonparametric kernel regression proposed by Nadaraya (1965) and Watson (1964). For this purpose the nonparametric estimate of the regression function using the conditional and unconditional biased corrected CRS environmental efficiency estimates has been adopted. Furthermore, figure 2 presents their variability bounds of pointwise error bars using asymptotic standard error formulas (Hayfield and Racine, 2008).

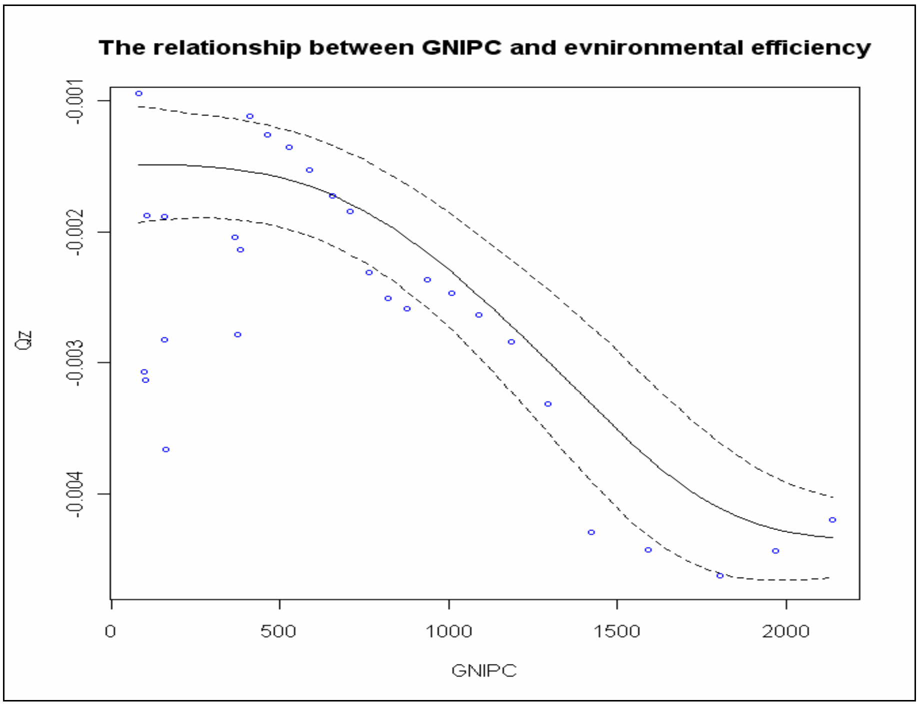
Figure 1: China's environmental efficiency scores for 1965-2009



As such it illustrates the effect of 'Z' (i.e. GNI per capita) under CRS assumption. As mentioned before, when the regression is decreasing, it indicates that 'Z' factor is unfavorable to China's environmental efficiency levels. In our case it appears clearly that the increase of China's GNI per capita levels have been influence negatively its environmental efficiency levels for the specified period. This result support the findings by Hilton and Levinson (1998), Rothman (1998) Gawande *et al.*

(2001) and Plassmann and Khanna (2006) suggesting that as China's GNIPC increase, creating in addition a consumption composition effect (Kellenberg, 2008, p.111) it would tend to increase emissions. It is clear that as long as the income levels in China increases the consumptive activities such as driving, the purchases of driving automobiles and the use of households' products will increase which in turn will have a direct negative effect on China's environmental efficiency levels. Finally, our results can not confirm a inverted 'U'-shape relationship between China's environmental efficiency levels and GNIPC. In addition it can be stated that as in Taskin and Zaim (2001) a negative monotonic relationship between economic growth (measured in GNIPC) and CO_2 environmental efficiency exists.

Figure 2: The effect of GNIPC on China's environmental efficiency for the years 1965-2009



4. Conclusions

Our paper analyses the relationship between China's environmental efficiency and GNI per capita levels. Tthe contribution of this paper to the literature is threefold. Firstly it models China's environmental efficiency for the time period of 1965 to 2009 in an environmental production function framework following the theoretical framework of Baumol and Oates (1988), Fontein *et al.*, (1994) and Stockey (1996) in a DEA formulation treating China's CO_2 emissions as controllable input as has been indicated by several authors (Pitman, 1981; Cropper and Oates, 1992; Reinhard *et al.*, 2000; Dyckhoff and Allen, 2001; Hailu and Veeman, 2001; Korhonen and Luptacik, 2004; Tsolas, 2005; Mandal and Madheswaran, 2010). Secondly it contributes to the existing literature (Zaim and Taskin, 2000; Taskin and Zaim, 2001; Zofio and Prieto, 2001; Zaim 2004; Managi, 2006; Yörük and Zaim, 2006; Picazo-Tadeo and García-Reche, 2007, Halkos and Tzeremes, 2009a) by investigating the existence of EKC hypothesis by modeling the effect of China's GNIPC levels on the obtained environmental performance indicators for a large period of time. Finally, and with respect to the methodologies applied our paper uses the latest advances of DEA analysis as has been introduced by (Daraio and Simar, 2005, 2007a, 2007b; Jeong *et al.*, 2010) in combination with the inferential approach introduced by Simar and Wilson (1998, 2000a, 2000b) and in order to overcome the traditional misspecification and measurement problems of the two stage DEA studies (Simar and Wilson, 2007, 2011). From that respect this paper demonstrates empirically for the case of China, how per capita income can influence China's CO_2 environmental efficiency levels.

Finally, the results support the findings obtained by several studies (Kim, 2001; Lu, 2005; Schreus, 2008) indicating that China has made several attempts to reduce its pollution levels after the end of Cold War in 1989. Furthermore, our findings suggest that there is a negative monotonic relationship between China's economic growth (measured in GNIPC) and CO_2 environmental efficiency levels (Taskin and Zaim, 2001). In addition strong support has been found for several other studies (Hilton and Levinson, 1998; Rothman, 1998; Gawande *et al.,* 2001; Plassmann and Khanna, 2006; Kellenberg, 2008) indicating that when per capita income increase then emissions tend to increase dramatically due to consumption composition effect, which in our case affect negatively China's environmental efficiency levels.

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