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Halkos, George and Tzeremes, Nickolaos

University of Thessaly, Department of Economics

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By

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

University of Thessaly, Department of Economics,

Korai 43, 38333, Volos, Greece

Abstract

By using conditional directional distance functions this paper investigates the effect of regional economic growth on regions' environmental efficiency in greenhouse gas emissions. A sample of ninety eight regions (NUTS 2 level) from Germany, France and the U.K. has been used and regional environmental inefficiencies have been obtained using both the unconditional and conditional output directional distance functions. The results reveal that German regions have the highest environmental efficiency levels. In addition it appears that the effect of regional economic growth on regions' environmental efficiency levels varies between regions and countries due to different national administrative arrangements on the implementation of environmental policies.

Keywords: Regional environmental efficiency; directional distance function; stochastic kernel; nonparametric regression.

JEL classification: C6; R11; R15; Q5; Q56.

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

1. Introduction

The link between environmental quality and economic growth has been an open research issue among the scholars for several years. Since the pioneer study by Kuznets (1955) who showed that income disparities first rise and then begin to fall during economic development stages, many studies tried to link a similar type of relationship between economic growth (in per capita terms) and environmental degradation. In a country level, the earlier studies by Selden and Song (1994) and Grossman and Kruger (1995) found an inverted U-type (Environmental Kuznets Curve-EKC) relationship between economic activity and environmental quality. Over the years this finding has found support by several country level studies (among others Ekins, 1997; Stern, 1998; 2002; 2004; Ansuategi and Perrings, 2000; Cavlovic et al, 2000; Andreoni and Levinson, 2001; Antweiler et al, 2001; Bulte and van Soest, 2001; Dasgupta et al, 2002; Halkos, 2003).

However, according to Batabyal and Nijkamp (2004, p. 295) the nexus between environmental quality, economic activity and growth has been examined mostly in a non-regional setting. According to Rupasingha et al (2004) all the EKC country level studies have ignored the spatial relations among the units. The importance of spatial dimensions in environmental measures has been highlighted by several studies (Bockstael, 1996; Goodchild et al, 2000; Anselin, 2001). Anselin (2001) suggests that country level environmental studies can be biased due to the scale mismatch of the various data used. This shortcoming has been also highlighted by several authors on studies examining the EKC hypothesis with the use of country level data (Grossman and Krueger, 1995; Stern et al, 1996; Carson et al, 1997).

In addition, spatial heterogeneities themselves can create scale mismatches due to the existence of different spatial patterns of economic development (Le Gallo and Ertur, 2003). Therefore, environment and space, or environmental quality and regional development are interrelated and this interrelation is in turn reflected on regional environmental policy. Batabyal and Nijkamp (2004) suggested the importance of regional environmental policy as being a tradeoff between economic development and environmental quality.

One of the first studies considering a theoretical model of multiregional growth, environmental processes, and multiregional trade was conducted by van den Bergh and Nijkamp (1998) indicating that when multiregional externalities exist, then it may not be possible to sustain growth in either a regional or in the global system. However the tradeoff between environmental quality and economic development has been first modeled by Färe et al (1989) with the use of distance functions in a nonparametric setting. It was the first model using distance functions measuring environmental technology in a production function framework. Additionally the model has treated pollutant as output of the production process and by imposing strong and weak disposability developed environmental performance indicators (hereafter EPIs).

Later, Tyteca (1996, 1997) introduced another EPI based on the same principles as Färe et al (1989) but with different assumptions. Since then, the construction of EPIs has been introduced by several papers that incorporate them into their analysis. Moreover, Chung et al. (1997) using the weak disposability assumption of outputs constructed a Malmquist–Luenberger index, creating for the first time environmental productivity indexes. In addition a vast amount of country level studies have been conducted examining the relationship between economic growth and environmental performance (among others Zaim and Taskin, 2000a; 2000b; 2000c; 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, 2009; 2011).

However, the majority of country level studies trying to relate environmental efficiency levels variations with economic growth involve a regression type second stage analysis. According to Simar and Wilson (2007, 2011) several assumptions regarding the data generating process (most of the times unsupported by economic data) are needed in order for the researchers to perform second-stage regressions involving DEA efficiency scores. In addition most of the two-stage DEA studies regard that separability condition between the input–output space and the space of the exogenous factors holds. Therefore they assume that these factors (external/exogenous to the environmental production process) have no influence on the attainable set, affecting only the probability of being more or less efficient (Bădin et al, 2010, p.634). Finally, as reported by Daraio et al (2010) the exogenous variables affect directly the shape of the distribution of the inefficiencies but also the production possibilities themselves.

Therefore the contribution of this study to the existing literature is twofold. First by applying the methodology introduced in the study by Simar and Vanhems (2012) modifies the "classic" directional distance function model (Färe and Grosskopf, 2004) incorporating bad outputs in order to account directly for the effect of economic growth into the environmental production process. More specifically, we propose a conditional directional distance function model which is able to treat bad outputs in productivity analysis but also takes into account directly the effect of economic growth. As a result we can model the effect of economic growth on environmental efficiency avoiding all the 'unrealistic' assumptions involved in most of the two-stage DEA formulations (Simar and Wilson, 2007; 2011). Secondly, we apply those conditional directional distance functions in a sample of ninety eight regions (at NUTS 2 level) of the three largest European economies (i.e. France, Germany and the U.K.) in order to investigate in a regional level how regional environmental efficiency in greenhouse gas emissions can be affected by regions' economic growth levels. In addition with the application of several kernel regression techniques our paper analyses for the first time at regional level the link between environmental efficiency in greenhouse gas emissions and economic development.

The structure of the paper is as follows. Section two presents the proposed methodology. Section three analyses the data and variables used, whereas section four presents analytically the results obtained from the analysis. Finally the last section concludes the paper.

2. Methodology

2.1 Directional distance functions for measuring regional environmental efficiency

Following the model proposed 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 outputs $u \in \Re_{+}^{K}$ and desirable outputs $v \in \Re_{+}^{M}$. Then in order to determine the environmental technology several assumptions are needed to be taken following Shephard (1970), 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. $(v,u) \in P(x)$ and $0 \leq \theta \leq 1$ then $(\theta v, \theta u) \in P(x)$ (i.e. the outputs are weakly disposable) and

2. $(v,u) \in P(x)$, $u = 0$ implies that $v = 0$ (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 it can be obtained only by a simultaneously 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 the data envelopment analysis (DEA) framework.

Let $k = 1,...,K$ be the observations and then the environmental output can be formalized as:

$$\begin{aligned} P(x) = \Big\{(v,u): & \sum_{k=1}^{K} \omega_k v_{km} \geq v_m, m = 1,...,M, \\ & \sum_{k=1}^{K} \omega_k u_{kj} = u_j, j = 1,...,J, \\ & \sum_{k=1}^{K} \omega_k x_{kn} \leq x_n, n = 1,...,N, \\ & \omega_k \geq 0, k = 1,...,K\Big\} \end{aligned} \tag{1}$$

$\omega_k, k = 1,...,K$ indicate the intensity variables which are not negative and imply constant return to scale[1]. The inequality on the good outputs and the equality on the bad outputs help us to impose the weak disposability assumption and only strong disposability of good outputs. However the null-jointness is imposed by the following restrictions on bad outputs:

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

[1] Following Zelenyuk and Zheka (2006, p.149) our regional environmental efficiency measurement follows the most common assumption made in Economics which is the constant returns to scale (CRS) assumption. In addition the CRS assumption provides us with greater discriminative power among the examined regions. As well, according to Picazo-Tadeo et al (2012, p.802) from an ecological perspective, economic activity is commonly characterised by constant returns to scale. Still if a researcher wants to impose variables returns to scale (VRS) in this model, it is suggested to read first the remarks raised by Kuosmanen (2005), Färe and Grosskopf (2009), Kuosmanen and Podinovski (2009) and Podinovski and Kuosmanen (2011).

Furthermore, we apply the directional distance function approach as in Chung et al (1997) and in order to be able to reduce bad and expand good outputs[2]. In order to be able to model that in the directional distance function setting we use a direction vector $g=\left(g_v,-g_u\right)$, where $g_v=1$ and $-g_u=-1$. Then the efficiency score for a region k' can be obtained from:

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

or as the solution to the following linear problem:

$$\begin{aligned} &D\left(x^{k'},v^{k'},u^{k'};g_v,g_u\right)=\max\beta \\ &s.t.\quad \sum_{k=1}^{K}\omega_k v_{km}\geq v_{k'm}+\beta g_{vm}, m=1,...,M, \\ &\qquad \sum_{k=1}^{K}\omega_k u_{kj}=u_{k'j}-\beta g_{uj}, j=1,...,J, \\ &\qquad \sum_{k=1}^{K}\omega_k x_{kn}\leq x_{k'n} \\ &\qquad \omega_k\geq 0, k=1,...,K. \end{aligned} \qquad (4).$$

Efficiency is next indicated when $D\left(x^{k'},v^{k'},u^{k'};g_v,g_u\right)=0$ and inefficiency by $D\left(x^{k'},v^{k'},u^{k'};g_v,g_u\right)>0$.

2.2 Conditional directional distance functions incorporating bad outputs

Following Daraio and Simar (2005) who extent the probabilistic formulation of the production process first introduced by Cazals et al (2002)[3], let the joint probability measure of $\left(X,Y^{v,u}\right)$ and the joint probability function of $H_{XY^{v,u}}(.,.)$ be defined as[4]:

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[2] This is the most common assumption made for directional distance functions when measuring environmental efficiency levels. However, different directions can be chosen in order for the researcher to test the environmental efficiency under different environmental policy scenarios (see among others Picazo-Tadeo et al, 2012; Halkos and Tzeremes, 2012).
[3] For the theoretical background and the asymptotic properties of nonparametric conditional efficiency measures see Jeong et al (2010).

$$H_{XY^{v,u}}\left(x, y^{v,u}\right) = \text{Prob}\left(X \le x, Y^{v,u} \ge y^{v,u}\right) \qquad (5).$$

In addition the following decomposition can be obtained as:

$$H_{XY^{v,u}}\left(x, y^{v,u}\right) = \text{Prob}\left(Y^{v,u} \ge y^{v,u} \middle| X \le x\right)\text{Prob}\left(X \le x\right) = S_{Y^{v,u}|X}\left(y^{v,u} \middle| x\right)F_X\left(x\right) \qquad (6),$$

where $F_X(x) = \text{Prob}(X \le x)$ and $S_{Y^{v,u}|X}\left(y^{v,u} \middle| x\right) = \text{Prob}\left(Y^{v,u} \ge y^{v,u} \middle| X \le x\right)$.

As well let $Z \in R^r$ denote the exogenous factors to the production process (in our case is the GDP per capita-GDPPC). Then equation (5) becomes:

$$H_{XY^{v,u}|Z}\left(x, y^{v,u} \middle| z\right) = \text{Prob}\left(X \le x, Y^{v,u} \ge y^{v,u} \middle| Z = z\right) \qquad (7),$$

which completely characterizes the production process. According to Daraio and Simar (2005; 2006; 2007) the following decomposition can be derived:

$$\begin{aligned} H_{XY^{v,u}|Z}\left(x, y^{v,u} \middle| z\right) &= \text{Prob}\left(Y^{v,u} \ge y^{v,u} \middle| X \le x, Z = z\right)\text{Prob}\left(X \le x \middle| z\right) \\ &= S_{Y^{v,u}|X,Z}\left(y^{v,u} \middle| x, z\right)F_{X|Z}\left(x \middle| z\right) \end{aligned} \qquad (8).$$

The estimator of the conditional survival function introduced above can be obtained from:

$$\hat{S}_{Y^{v,u}|X,Z}\left(y^{v,u} \middle| x, z\right) = \frac{\sum_{i=1}^{n} I\left(Y_i^{v,u} \ge y^{v,u}, X_i \le x\right)K_h\left(Z_i, z\right)}{\sum_{i=1}^{n} I\left(X_i \le x\right)K_h\left(Z_i, z\right)} \qquad (9),$$

where $K_h(Z_i, z) = h^{-1}K((Z_i - z)/h)$ with $K(.)$ being a univariate kernel defined on a compact support (Epanechnikov in our case) and h is the appropriate bandwidth calculated following Bădin et al (2010)[5].

Recently Simar and Vanhems (2012) developed the probabilistic characterization of directional distance function taking the general form of:

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[4] For simplicity of presentation $Y^{v,u}$ symbolizes bad (u) and good (v) outputs.

[5] The calculation of bandwidth by Bădin et al (2010) is based on the Least Squares Cross Validation (LSCV) criterion introduced by Hall et al (2004) and Li and Racine (2007).

$$D(x, y; g_x, g_y) = \sup\{\beta > 0 | H_{XY}(x - \beta g_x, y + \beta g_y) > 0\} \quad (10)$$

and the conditional directional distance function of (x, y) conditional on $Z = z$ can then be defined as:

$$D(x, y; g_x, g_y | z) = \sup\{\beta > 0 | H_{XY|Z}(x - \beta g_x, y + \beta g_y | Z = z) > 0\} \quad (11).$$

Based on those developments the probabilistic form of Färe and Grosskopf 's (2004) model (presented previously) measuring environmental efficiency will take respectively the form of:

$$D\left(x^{k'}, v^{k'}, u^{k'}; g_v, g_u\right) = \sup\left\{\beta > 0 \middle| H_{XY^{v,u}}\left(x^{k'}, v^{k'} + \beta g_v, u^{k'} - \beta g_u\right) > 0\right\} \quad (12).$$

Besides the conditional form of the model will take the form of

$$D\left(x^{k'}, v^{k'}, u^{k'}; g_v, g_u \middle| z\right) = \sup\left\{\beta > 0 \middle| H_{XY^{v,u}|Z}\left(x^{k'}, v^{k'} + \beta g_v, u^{k'} - \beta g_u \middle| Z = z\right) > 0\right\} \quad (13).$$

Finally, the DEA program for the environmental efficiency score for a region k' when using the conditional output oriented directional distance function can be calculated as:

$$\begin{aligned} & D\left(x^{k'}, v^{k'}, u^{k'}; g_v, g_u \middle| z\right) = \max \beta \\ & s.t. \quad \sum_{\substack{k=1,\dots,K| \\ |Z_k - z| \le h}} \omega_k v_{km} \ge v_{k'm} + \beta g_{vm}, m = 1, \dots, M, \\ & \sum_{\substack{k=1,\dots,K| \\ |Z_k - z| \le h}} \omega_k u_{kj} = u_{k'j} - \beta g_{uj}, j = 1, \dots, J, \\ & \sum_{\substack{k=1,\dots,K| \\ |Z_k - z| \le h}} \omega_k x_{kn} \le x_{k'n} \\ & \omega_k \ge 0, k = 1, \dots, K \text{ such that } |Z_k - z| \le h. \end{aligned} \quad (14)$$

As shown previously efficient regions will be indicated when $D\left(x^{k'}, v^{k'}, u^{k'}; g_v, g_u \middle| z\right) = 0$ and inefficient regions will respectively be specified by values of $D\left(x^{k'}, v^{k'}, u^{k'}; g_v, g_u \middle| z\right) > 0$.

As can be realised the results obtained from equation (14) are different compared to the results derived from equation (4) since the exogenous variable Z is assumed that influences directly the shape of the environmental production frontier (i.e., the conditional directional distance function in (14) does not assume a separability condition). Therefore the inefficiency and efficiency estimates obtained are determined by the inputs, the good, the bad outputs and the exogenous variable accordingly. As a result the conditional directional distance function is obtained only by points taking their Z value in the neighborhood of z (Daraio and Simar, 2007).

Additionally from the researcher's point of view the most crucial part of the proposed model is the estimation of bandwidth (h) which determines the 'neighborhood' of z. As explained earlier we followed the approach introduced by Bădin et al (2010) in order to calculate the bandwidth which is based on Least Squares Cross Validation (LSCV) criterion[6].

2.3 Determining the effect of regional economic growth

In order to identify the effect of regional economic growth-GDPPC (Z) on regions environmental inefficiency (REI) levels without specifying in prior any functional relationship, our paper applies a nonparametric regression in the principles of Daraio and Simar (2005; 2006; 2007). When Z is univariate (as in our case), a scatter plot of the ratio $D\left(x, v, u; g_v, g_u \middle| z\right) / D\left(x, v, u; g_v, g_u\right)$ against Z and its smooth

[6] Bădin et al (2010, p. 640) provide the Matlab codes which are needed in order to compute the appropriate bandwidth. The codes are referring to the output orientation as in our case.

nonparametric regression line would be able to describe the effect of Z on regions' inefficiency levels.

Following Jeong et al (2010) a local linear kernel estimator is applied in order to reveal the effect of regional GDPPC on regions' REI levels since the local linear kernel estimator is less sensitive to edge effects. According to Fan (1992, 1993) and Fan and Gijbels (1995), the kernel weighted local linear model will have the form of:

$$Q_k^z = \alpha + \beta'(Z_k - z) + \varepsilon_k \tag{15}$$

where $Q_k^z = \dfrac{D\left(x^k, v^k, u^k; g_v, g_u \middle| Z_k\right)}{D\left(x^k, v^k, u^k; g_v, g_u\right)}$, and ε_k is the error term.

Moreover, by using the $Z_k - z$ instead of Z_k the intercept will be equal to $E\left(Q_k^z \middle| Z_k = z\right)$. If we fit the linear regression through the observations $|Z_k - z| \leq h$ this can be written as:

$$\min_{\alpha,\beta} \sum_{k=1}^{K} \left(Q_k^z - \alpha - \beta'(Z_k - z)\right)^2 I\left(|Z_k - z| \leq h\right) \tag{16}$$

or by setting $\phi_k = \begin{pmatrix} 1 \\ Z_k - z \end{pmatrix}$ then the (locally) weighted regression of Q_k^z on Z_k will has the explicit expression of:

$$\begin{aligned} \begin{pmatrix} \hat{\alpha}(z) \\ \hat{\beta}(z) \end{pmatrix} &= \left(\sum_{k=1}^{K} I\left(|Z_k - z| \leq h\right)\phi_k \phi_k{}'\right)^{-1} \left(\sum_{k=1}^{K} I\left(|Z_k - z| \leq h\right)\phi_k Q_k^z\right) \\ &= \left(\sum_{k=1}^{K} \mathrm{K}\left(H^{-1}(Z_k - z)\right)\phi_k \phi_k{}'\right)^{-1} \left(\sum_{k=1}^{K} \mathrm{K}\left(H^{-1}(Z_k - z)\right)\phi_k Q_k^z\right) \end{aligned} \tag{17}$$

In equation (17) $\mathrm{K}(.)$ represents the kernel function and h the bandwidth (or smoothing parameter) calculated by the least squares cross-validation data driven method as suggested by Li and Racine (2004)[7]. Additionally, following the nonparametric regression significance test proposed by Racine et al (2006) and Racine (2008, p.67) we investigate the statistical significance of Z explaining the variations of Q[8].

Furthermore we follow the lines of the interpretation given for the visualization effect derived as has been presented by Daraio and Simar (2005; 2006; 2007) in order to analyze the global influence of the exogenous variable (Z) on the environmental production process. Since we use output oriented conditional and unconditional directional distance functions an increasing regression line will indicate a favorable exogenous factor, where as a decreasing regression line will indicate an unfavorable factor. When the exogenous variable Z is favorable to regions' environmental inefficiency levels we expect that the value of $D(x,v,u;g_v,g_u|z)$ will be much smaller compared to $D(x,v,u;g_v,g_u)$ for small values of Z compared to larger values of Z. Therefore the ratio $D(x,v,u;g_v,g_u|z)/D(x,v,u;g_v,g_u)$ will increase with Z, on average. However when Z is unfavorable to the environmental production process, the value of $D(x,v,u;g_v,g_u|z)$ will be much smaller compared to the values of $D(x,v,u;g_v,g_u)$ for larger values of Z. As a result the regression line of $D(x,v,u;g_v,g_u|z)/D(x,v,u;g_v,g_u)$ over Z will be decreasing.

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[7] As previously pointed the selection of bandwidth h is very critical for our nonparametric regression analysis because when $h \to \infty$ (i.e. the smoothing is increased) the local linear estimator collapses to OLS regression of Q_k^z on Z_k.

[8] For the significance test we applied the bootstrap procedures as described by Racine (1997).

3. Data and variables

In our analysis we are using regional data collected from two different regional databases (EUROSTAT[9] and OECD[10]) for the year 2007. The data concern the regions of the three largest EU economies (i.e. Germany, France and the U.K.). Most of the studies measuring regional environmental efficiencies analyze administrative regions (in NUTS 2 level)[11] in order to grasp the effect of regional regulatory environmental style within the countries (Knill and Lenschow, 1998). Similarly, our analysis is referring to NUTS 2 level for 22 French, 39 German and 37 U.K. regions[12]. In total our study constructs the regional environmental efficiency (REE) indicators of 98 European regions.

Based on several other studies similar to ours (Färe et al, 1989; 1996; 2004; Färe and Grosskopf 2003; 2004; Chung et al, 1997; Tyteca, 1996; 1997; Taskin and Zaim, 2001; Zofio and Prieto, 2001; Zaim, 2004; Picazo-Tadeo et al, 2005; Managi, 2006; Yörük and Zaim, 2006; Picazo-Tadeo and García-Reche, 2007) in order to model regional environmental efficiency we use two inputs. These are the total regional labour force (employed people-all NACE activities in thousands)[13] and regional capital stock (millions of euro). Regional capital stock for the year 2007 is

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[9] Available from:
http://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/regional_statistics/data/main_tables.

[10] Available from: http://stats.oecd.org/Index.aspx?DataSetCode=REG_LAB_TL3.

[11] According to the European Parliament NUTS 2 regulation defines the regions with population between 80000 and 3 million. As a result NUTS 2 level classification is based on the administrative divisions applied in the Member States (for more information see: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Regional_yearbook_introduction#The_NUTS_classification).

[12] Details for regions at NUTS 2 level see:
for France: http://en.wikipedia.org/wiki/NUTS_of_France,
for Germany: http://en.wikipedia.org/wiki/NUTS_of_Germany,
for U.K.: http://en.wikipedia.org/wiki/NUTS_of_the_United_Kingdom.

[13] The statistical classification of economic activities in the European Community, abbreviated as NACE, designates the nomenclature of economic activities in the European Union. (see http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:Statistical_classification_of_economic_activities_in_the_European_Community_%28NACE%29).

not available; therefore we calculated it following the perpetual inventory method (Feldstein and Foot, 1971; Epstein and Denny, 1980) as:

$$K_t = I_t + (1-\delta)K_{t-1} \tag{18}$$

where K_t and K_{t-1} the regional gross capital stock in the current and in the previous years respectively; I_t is the regional gross fixed capital formation and δ represents the depreciation rate of capital stock. Finally, by following the study by Ezcura et al, (2009) we set δ equal to 5%.

Likewise our study uses regional gross domestic product (millions euros at constant prices) as good output and three greenhouse gases (GHGs) as bad outputs (realised from all NACE activities). More analytically we use data from the European Environmental Agency[14] that refer to the regional quantities of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) measured in metric tones. Greenhouse gases (GHGs) include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as high Global Warming Potential gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). CO_2 emissions from the burning of fossil fuels and the change in the use of human land are considered as the most important anthropogenic effect. Methane and nitrous oxide are naturally present in the atmosphere. Methane is caused by emissions from landfills, livestock, rice farming and fertilizers. These three gases are among the most significant GHGs (Halkos, 2010).

Then in our second stage analysis and in order to test the link between regional environmental efficiency and regional economic growth, we follow several other regional studies (He, 2008; Diao et al, 2009; Brajer et al, 2011) using regional GDP per capita (GDPPC) (measured in euro) as a proxy of regional economic growth.

[14] Available from: http://prtr.ec.europa.eu.

Table 1 presents the descriptive statistics of the variables used. As can be realized there are a lot of disparities among the ninety eight regions of our analysis.

Table 1: Descriptive statistics of variables used

	Capital Stock	Labour Force	GDP	GDPPC	CH_4	CO_2	N_2O
German regions (39)							
Mean	8258599.400	953.380	60201.290	28389.470	7960.500	11540020.970	1041.887
Std	539339.240	498.040	40430.320	6321.470	18475.170	18940299.980	2901.570
Min	7391667.210	253.000	12402.000	19200.000	123.000	31797.000	11.600
Max	9187590.310	2301.900	181587.000	47600.000	105241.000	92461000.000	15210.000
U.K. regions (37)							
Mean	9417516.083	839.897	46894.784	31788.889	14302.167	6676305.556	244.908
Std	510416.259	518.549	40521.327	12318.204	10902.680	8533627.046	504.685
Min	8607011.688	234.300	9413.000	21200.000	1440.000	121000.000	12.900
Max	10318455.890	2772.800	242892.000	96600.000	49168.000	33536000.000	2110.000
French regions (22)							
Mean	8679791.253	968.610	62824.476	25614.286	6891.857	5800761.905	897.024
Std	323301.124	569.897	40464.665	1833.654	8691.427	7838026.141	1835.287
Min	8168690.492	78.500	6857.000	22800.000	220.000	215000.000	12.400
Max	9210925.427	2589.500	182276.000	29900.000	40003.000	23641000.000	7282.000

4. Empirical Results

Following the methodology presented previously, table 2 presents the regional environmental inefficiency (REI) scores [$D\left(x,v,u;g_v,g_u\right)$] of the ninety eight regions shorted by country. It appears that thirty regions out of ninety eight are reported to be environmental efficient (i.e. with environmental inefficiency score equal to 0). There are eight efficient regions from the U.K., four from France and eighteen from Germany. The U.K.'s environmental efficient regions in greenhouse gases are Tees Valley and Durham, Greater Manchester, North Yorkshire, Herefordshire, Worcestershire and Warwickshire, Inner London, Surrey, East and West Sussex, West Wales and The Valleys and South Western Scotland. The French environmental efficient regions are Île de France, Champagne-Ardenne, Alsace and Bretagne. Finally, the environmental efficient regions in Germany are Karlsruhe, Tübingen, Oberbayern, Niederbayern, Oberpfalz, Oberfranken, Mittelfranken, Schwaben, Berlin, Bremen, Hamburg, Mecklenburg-Vorpommern, Braunschweig, Düsseldorf, Köln, Münster, Rheinhessen-Pfalz and Saarland.

In addition table 2 reveals that the five regions with the highest environmental inefficiencies (i.e. lowest regional environmental efficiency) in France are Auvergne (0.5663), Bourgogne (0.5886), Nord - Pas-de-Calais (0.6354), Picardie (0.7063) and Lorraine. In Germany the five regions with highest regional environmental inefficiency scores are Leipzig (0.724), Brandenburg – Südwest (0.7376), Arnsberg (0.7662), Brandenburg-Nordost (0.8479) and Sachsen-Anhalt (0.8479). Finally, in the U.K. the five lowest performances have been recorded for Derbyshire and Nottinghamshire (0.8912), Shropshire and Staffordshire (0.8965), Lincolnshire (0.9142), East Yorkshire and Northern Lincolnshire (0.9207) and Cumbria (0.9214).

When looking at the descriptive statistics the mean REI level of all the ninety eight regions is 0.374 with a standard deviation of 0.33. This indicates that on average terms regions can reduce their greenhouse gas emissions by 37% while at the same time can increase their GDP levels by the same proportion. It appears that 48 regions in total (out of 98) have inefficiency levels below the average recorded value. In addition when looking at the descriptive statistics for German regions we can observe that their mean regional environmental inefficiency level is the lowest (0.252) indicating that German regions can decrease their regional greenhouse emissions by 25% and simultaneously can increase their regional GDP level by the same amount. Moreover, French regions are reported to have 0.345 mean regional environmental inefficiency score, whereas the U.K. regions are reported to have the highest mean regional environmental inefficiency score (0.52). It is recorded that the most environmental efficient regions are the German regions and the ones with the lowest performance are the U.K. regions.

Our results confirm the findings by Knill and Lenschow (1998) suggesting that the national administrative arrangements on the implementation of EU environmental policies are completely different between the U.K. and the Germany. Germany has a hierarchical substantive low flexibility state intervention on environmental policy whereas the U.K. has a more self-regulatory, procedural with high flexibility/discretion type state intervention (Knill and Lenschow, 1998; p.598). Besides, French regions appear to have regional environmental inefficiencies values between these two ‘extremes’ (in average terms) which are reflecting an additional different national administrative arrangement on the implementation of EU environmental policies.

In addition to table 2, table 3 presents the results obtained when we take into account the effect of GDP per capita as a proxy of regional economic growth (He, 2008; Diao et al, 2009; Brajer et al, 2011). It appears that under the conditional estimates thirty seven regions appear to have zero regional environmental inefficiency. The mean environmental inefficiency score for the conditional measures is 0.317, indicating that in average terms under the effect of regional GDPPC the examined regions can increase by 31% their GDP levels and can decrease their greenhouse emission by the same proportion.

Table 2: Regions' environmental inefficiency levels

UK regions (37)	$D(x,v,u;g_v,g_u)$	French regions (22)	$D(x,v,u;g_v,g_u)$	German regions (39)	$D(x,v,u;g_v,g_u)$
Tees Valley and Durham	0.0000	*Île de France*	0.0000	*Karlsruhe*	0.0000
Greater Manchester	0.0000	*Champagne-Ardenne*	0.0000	*Tübingen*	0.0000
North Yorkshire	0.0000	*Alsace*	0.0000	*Oberbayern*	0.0000
Herefordshire, Worcestershire and Warwickshire	0.0000	*Bretagne*	0.0000	*Niederbayern*	0.0000
Inner London	0.0000	*Limousin*	0.1149	*Oberpfalz*	0.0000
Surrey, East and West Sussex	0.0000	*Franche-Comté*	0.1578	*Oberfranken*	0.0000
West Wales and The Valleys	0.0000	*Rhône-Alpes*	0.1884	*Schwaben*	0.0000
South Western Scotland	0.0000	*Languedoc-Roussillon*	0.1913	*Berlin*	0.0000
West Midlands	0.0893	*Corse*	0.2203	*Bremen*	0.0000
Kent	0.1532	*Aquitaine*	0.2474	*Hamburg*	0.0000
Outer London	0.2884	*Midi-Pyrénées*	0.2598	*Mecklenburg-Vorpommern*	0.0000
Devon	0.4173	*Provence-Alpes-Côte d'Azur*	0.4243	*Braunschweig*	0.0000
West Yorkshire	0.4568	*Haute-Normandie*	0.4834	*Düsseldorf*	0.0000
Merseyside	0.4630	*Centre*	0.4864	*Köln*	0.0000
Dorset and Somerset	0.4706	*Poitou-Charentes*	0.5053	*Münster*	0.0000
Bedfordshire and Hertfordshire	0.4846	*Basse-Normandie*	0.5066	*Rheinhessen-Pfalz*	0.0000
Northern Ireland (UK)	0.5401	*Pays de la Loire*	0.5486	*Saarland*	0.0000
Gloucestershire, Wiltshire and Bristol/Bath area	0.5565	*Auvergne*	0.5663	*Mittelfranken*	0.0000
South Yorkshire	0.5734	*Bourgogne*	0.5886	*Darmstadt*	0.0313
Leicestershire, Rutland and Northamptonshire	0.6812	*Nord - Pas-de-Calais*	0.6354	*Trier*	0.0449
Eastern Scotland	0.7063	*Picardie*	0.7063	*Unterfranken*	0.0763
Hampshire and Isle of Wight	0.7164	*Lorraine*	0.7685	*Stuttgart*	0.0873
Cornwall and Isles of Scilly	0.7406			*Schleswig-Holstein*	0.1982
Essex	0.7625			*Freiburg*	0.2047
Northumberland and Tyne and Wear	0.7626			*Kassel*	0.2198
East Anglia	0.7835			*Koblenz*	0.3344
North Eastern Scotland	0.7994			*Chemnitz*	0.5504
Lancashire	0.8135			*Weser-Ems*	0.5512
East Wales	0.8384			*Detmold*	0.5557
Berkshire, Buckinghamshire and Oxfordshire	0.8435			*Lüneburg*	0.5567
Highlands and Islands	0.8673			*Dresden*	0.5792
Cheshire	0.8773			*Gießen*	0.5982
Derbyshire and Nottinghamshire	0.8912			*Thüringen*	0.6415
Shropshire and Staffordshire	0.8965			*Hannover*	0.6585
Lincolnshire	0.9142			*Leipzig*	0.7240
East Yorkshire and Northern Lincolnshire	0.9207			*Brandenburg - Südwest*	0.7376
Cumbria	0.9214			*Arnsberg*	0.7662
				Brandenburg - Nordost	0.8479
				Sachsen-Anhalt	0.8479
Mean	*0.520*	*Mean*	*0.345*	*Mean*	*0.252*
Std	*0.345*	*Std*	*0.247*	*Std*	*0.310*
Min	*0.000*	*Min*	*0.000*	*Min*	*0.000*
Max	*0.921*	*Max*	*0.769*	*Max*	*0.848*
Despriptive statistics of all regions (98)					
Mean	*0.374*				
Std	*0.330*				
Min	*0.000*				
Max	*0.921*				

In the case of France, the environmental efficient regions under the effect of regional economic growth are Île de France, Champagne-Ardenne, Alsace, Bretagne and Rhône-Alpes. At the same time, the five regions with the lowest environmental performance are Bourgogne (0.6236), Nord - Pas-de-Calais (0.6316), Haute-Normandie (0.7055), Picardie (0.7276) and Lorraine (0.8151). Likewise French regions' average conditional environmental inefficiency value is 0.324, indicating that French regions can increase their GDP levels by 32% and simultaneously they can reduce their greenhouse emissions by the same proportion.

Finally in the case of Germany, twenty one regions are reported as environmentally efficient under the effect of regional GDPPC. These are the region of Stuttgart, Karlsruhe, Tübingen, Oberbayern, Niederbayern, Oberpfalz, Oberfranken, Schwaben, Berlin, Bremen, Hamburg, Darmstadt, Mecklenburg-Vorpommern, Braunschweig, Düsseldorf, Köln, Münster, Arnsberg, Rheinhessen-Pfalz, Saarland and Schleswig-Holstein. Then the five regions with the lowest conditional regional environmental performance are Gießen (0.5982), Sachsen-Anhalt (0.7277), Leipzig (0.7741), and Brandenburg – Nordost (0.8532) and Brandenburg Südwest (0.8533). On average terms it appears that German regions under the conditional environmental inefficiency measures have the lowest inefficiencies levels (0.202), indicating that they are able to decrease their greenhouse emissions by 20% and simultaneously are able to increase their GDP levels by the same proportion.

As a general conclusion when comparing the conditional and unconditional regional environmental inefficiencies estimates we can argue that the effect of regional GDPPC has decreased regions' inefficiency levels. The average overall inefficiency level (all regions) for the unconditional case is 0.374 whereas, for the conditional case is 0.317. Similarly we can observe differences between the conditional and unconditional estimates for the three countries. This finding verifies the fact that conditional measures are suitable for explaining efficiencies/inefficiencies because the environmental (exogenous) variable affects directly not only the shape of the distribution of the inefficiencies obtained but also the production possibilities themselves (Daraio et al, 2010).

In addition as explained earlier our study examines the effect of regional economic growth on the obtained regional environmental inefficiency levels by regressing GDPPC on Q_k^z in a nonparametric regression setting. We apply a nonparametric regression analysis in the principles of Daraio and Simar (2005), since nonparametric approaches can reveal structure in the data which might be missed when applying common parametric functional specifications (Li and Racine, 2007).

Furthermore we apply the nonparametric significance test developed by Racine et al. (2006) and Racine (2008) in order to measure if the variations of REI levels are statistically significant explained by the different regional GDPPC levels. Figure 1 illustrates the nonparametric estimate of the regression function between regional GDPPC and REI alongside with their variability bounds of point wise error bars using asymptotic standard error formulas (Hayfield and Racine, 2008) for all the regions (subfigure 1a), for German regions (subfigure 1b), for U.K. regions (subfigure 1c) and for French regions (subfigure 1d).

Table 3: Regions' conditional environmental inefficiency levels

UK regions (37)	$D(x,v,u;g_v,g_u\|z)$	French regions (22)	$D(x,v,u;g_v,g_u\|z)$	German regions (39)	$D(x,v,u;g_v,g_u\|z)$
Tees Valley and Durham	0.0000	*Île de France*	0.0000	*Stuttgart*	0.0000
Greater Manchester	0.0000	*Champagne-Ardenne*	0.0000	*Karlsruhe*	0.0000
North Yorkshire	0.0000	*Alsace*	0.0000	*Tübingen*	0.0000
Herefordshire, Worcestershire and Warwickshire	0.0000	*Bretagne*	0.0000	*Oberbayern*	0.0000
West Midlands	0.0000	*Rhône-Alpes*	0.0000	*Niederbayern*	0.0000
East Anglia	0.0000	*Limousin*	0.0619	*Oberpfalz*	0.0000
Inner London	0.0000	*Languedoc-Roussillon*	0.0748	*Oberfranken*	0.0000
Outer London	0.0000	*Midi-Pyrénées*	0.1137	*Schwaben*	0.0000
Surrey, East and West Sussex	0.0000	*Aquitaine*	0.1711	*Berlin*	0.0000
West Wales and The Valleys	0.0000	*Franche-Comté*	0.1954	*Bremen*	0.0000
South Western Scotland	0.0000	*Corse*	0.2265	*Hamburg*	0.0000
Kent	0.2464	*Provence-Alpes-Côte d'Azur*	0.2535	*Darmstadt*	0.0000
West Yorkshire	0.2620	*Centre*	0.3615	*Mecklenburg-Vorpommern*	0.0000
Merseyside	0.2895	*Pays de la Loire*	0.4648	*Braunschweig*	0.0000
South Yorkshire	0.2976	*Auvergne*	0.5689	*Düsseldorf*	0.0000
Bedfordshire and Hertfordshire	0.3786	*Poitou-Charentes*	0.5705	*Köln*	0.0000
Leicestershire, Rutland and Northamptonshire	0.4117	*Basse-Normandie*	0.5713	*Münster*	0.0000
Devon	0.4447	*Bourgogne*	0.6236	*Arnsberg*	0.0000
Dorset and Somerset	0.4706	*Nord - Pas-de-Calais*	0.6316	*Rheinhessen-Pfalz*	0.0000
Northern Ireland (UK)	0.4946	*Haute-Normandie*	0.7055	*Saarland*	0.0000
Gloucestershire, Wiltshire and Bristol/Bath area	0.5723	*Picardie*	0.7276	*Schleswig-Holstein*	0.0000
Eastern Scotland	0.6078	*Lorraine*	0.8151	*Mittelfranken*	0.0003
Lancashire	0.6135			*Trier*	0.0449
Northumberland and Tyne and Wear	0.6143			*Unterfranken*	0.1310
Essex	0.6455			*Freiburg*	0.1887
Hampshire and Isle of Wight	0.6470			*Koblenz*	0.2171
Cornwall and Isles of Scilly	0.7406			*Kassel*	0.2601
North Eastern Scotland	0.7418			*Thüringen*	0.3189
Berkshire, Buckinghamshire and Oxfordshire	0.7429			*Detmold*	0.3968
Shropshire and Staffordshire	0.7857			*Weser-Ems*	0.4227
East Wales	0.8037			*Dresden*	0.4712
Derbyshire and Nottinghamshire	0.8080			*Chemnitz*	0.4918
Cheshire	0.8355			*Lüneburg*	0.5494
Highlands and Islands	0.8673			*Hannover*	0.5811
Lincolnshire	0.8982			*Gießen*	0.5982
Cumbria	0.9005			*Sachsen-Anhalt*	0.7277
East Yorkshire and Northern Lincolnshire	0.9329			*Leipzig*	0.7741
				Brandenburg - Nordost	0.8532
				Brandenburg - Südwest	0.8533
Mean	*0.434*	*Mean*	*0.324*	*Mean*	*0.202*
Std	*0.338*	*Std*	*0.284*	*Std*	*0.284*
Min	*0.000*	*Min*	*0.000*	*Min*	*0.000*
Max	*0.933*	*Max*	*0.815*	*Max*	*0.853*
Despriptive statistics of all regions (98)					
Mean	*0.317*				
Std	*0.319*				
Min	*0.000*				
Max	*0.933*				

Subfigure 1a reveals that the effect of regional GDPPC on the ninety eight regions' REI levels has a negative nonlinear relationship[15]. It appears that when the regional GDPPC increases, regions' REI levels are also decreasing. As a result we can expect the higher the economic growth of a region the higher its environmental efficiency levels will be.

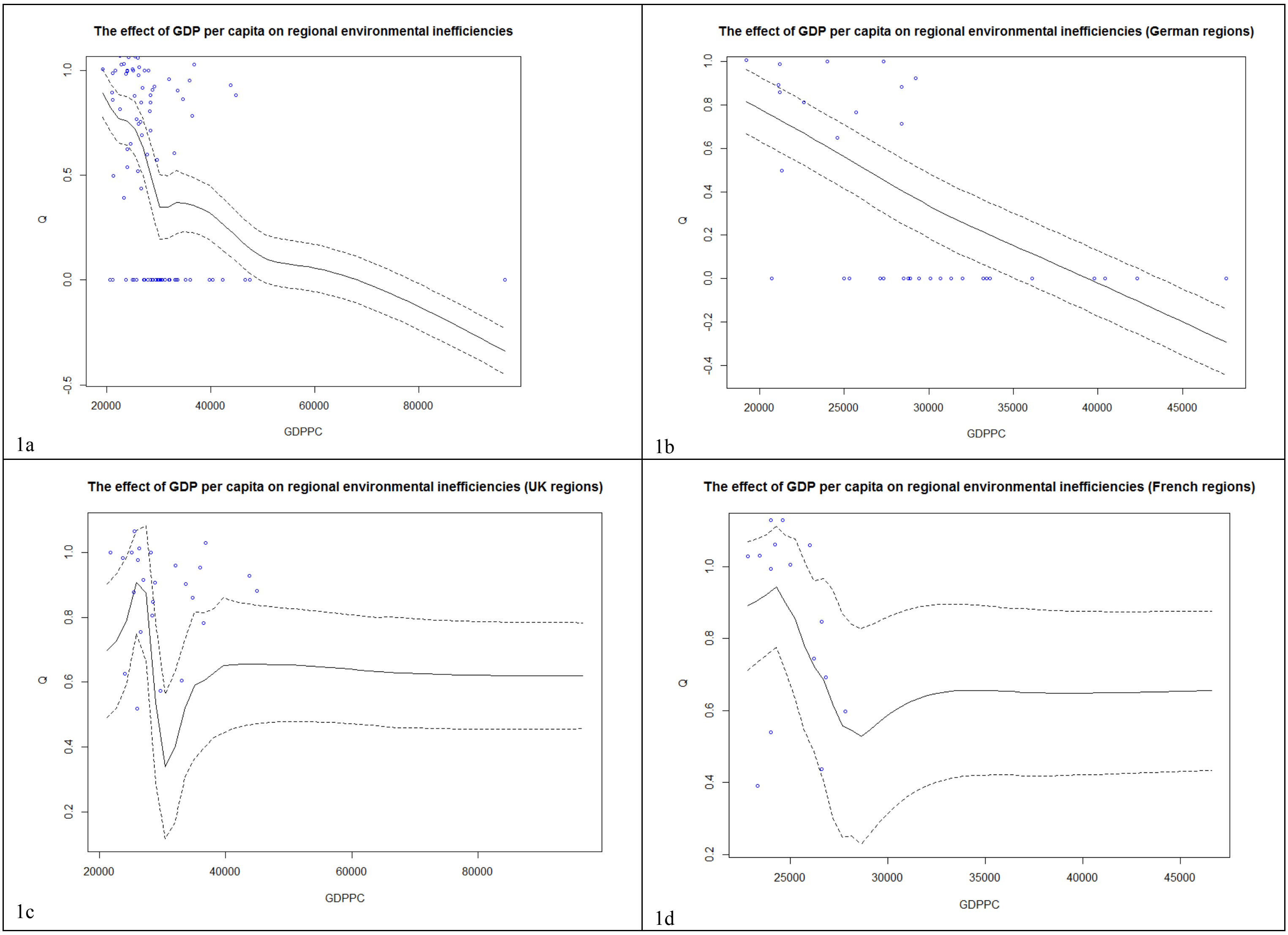
Moreover, when looking at the case of German regions (subfigure1b) we discover that the relationship between German regions' GDPPC and REI levels is again negative (almost a negative linear relationship). Therefore, as regional economic growth increases regions' REI levels will decrease accordingly (i.e. regions' environmental efficiency levels will increase). However, subfigure 1c reveals a different functional relationship between regions' GDPPC and REI levels for the case of U.K. regions[16]. It can be observed a mixed effect (highly nonlinear) for a large part of GDPPC (up to 40000€). As it appears there is a positive effect for regions' REI levels up to a certain point (27000€). Then between a certain length of GDPPC (27000€-30000€) a negative effect of GDPPC on U.K. regions' REI levels is recorded. In addition for GDPPC levels between 30000€-40000€ the effect becomes positive indicating an increase of REI levels (i.e. a decrease on regions environmental efficiency levels). After that point and for the largest part of U.K. regions' GDPPC the effect appears to be "almost" neutral.

Finally, in the case of French regions (subfigure 1d) the effect of regional GDPPC on REI values has similar shape compared to subfigure 1c[17]. Therefore the effect of regional economic growth has a positive effect to regions' REI levels up to

[15] Following the significance test (Racine et al, 2006; Racine, 2008) a bootstrapped *p-value* of 0.0000 was obtained indicating that regional GDPPC can explain the variations of REI levels among the ninety eight regions.
[16] We obtained a bootstrapped *p-value* of 0.0075 which indicates that regional GDPPC can explain the variations of REI levels for U.K. regions.
[17] We obtained a bootstrapped *p-value* of 0.0236 which indicates that regional GDPPC can explain the variations of REI levels for U.K. regions.

certain point (24200€) and then the effect becomes negative for certain GDPPC values (24200€-27900€). But after that level of GDPPC (27900€) the effect of regional economic growth on French regions' REI levels becomes neutral.

Figure 1: The effect of regional GDP per capita (GDPPC) on regions' environmental inefficiency levels (Q)



This result verifies the findings of several studies investigating the emissions-GDPPC relationship which have obtained similar results. For instance, He (2008) using panel regional data for 29 Chinese provinces for the time period of 1992-2003 found evidence of quadratic and cubic relationship between SO_2 emissions and

GDPPC. Similar results are also reported by Diao et al (2009) for the Zhejiang area of China for the time period of 1995-2005. In addition 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 GDPPC-pollution relationship differs by pollutant with some pollutants having periods of decline whiles others may be continuously increasing.

Our results reveal emphatically that regions' economic growth affects their environmental efficiency (inefficiency) levels differently since the environmental policies implications and implementations are different not only on country level but also on regional/administrative level.

5. Conclusions

Our paper contributes to the existing literature of environmental performance measurement in two distinct ways. First by applying the conditional directional distance function approach and the property of weak disposability our paper modifies the original model by Färe and Grosskopf (2004) in order to account for exogenous variables (in our case GDP per capita) into the environmental production process. Thus it provides consistent results avoiding common assumptions made by several two-stage DEA studies (Simar and Wilson, 2007; 2011).

A second contribution of our work is related to the empirical application of our proposed model which presents for the first time the measurement of spatial environmental heterogeneities in greenhouse emissions of ninety eight European regions (NUTS 2 level) of the three largest EU economies. The results from the conditional and unconditional directional distance functions demonstrate that there are a lot of environmental inefficiencies among the regions with German regions having higher environmental efficiency levels (on average terms) and U.K. regions having the lowest.

Additionally the disparity of regions' environmental inefficiencies in greenhouse emissions suggests that the national administrative arrangements on the implementation of EU environmental policies significantly differ among the examined countries and among their regions (Knill and Lenschow, 1998).

Likewise and by following the same principles as Daraio and Simar (2005; 2006; 2007), a local linear kernel estimator was applied in order for the effect of regional GDP per capita on the obtained regional environmental inefficiency levels to be examined. It appears that regional economic growth affects differently regions' environmental inefficiency levels in greenhouse emissions having a nonlinear relationship thus indicating that higher regional economic levels do not ensure higher environmental quality.

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