Pollution and economic growth: a maximum likelihood estimation of environmental Kuznets curve

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Abstract

As in Brock and Taylor (2011) in this paper we consider the importance of the relationship between the Environmental Kuznets Curve (EKC) Literature and the Economic Growth Theories. To address this issue we construct country production functions that directly incorporate CO_2 emissions as input and estimate them using Stochastic Frontiers. This approach differs from that of Brock and Taylor (2011) but is similar to the one followed by Koop (1998). By introducing the environmental "bads" directly in the production function, we can analyse their contribution to total output growth. We highlight an important contribution of CO_2 emissions to growth and find out that the EKC seems not to hold, at least for most countries.

JEL classification: Q53;

Keywords: Environmental Kuznets Curve, Stochastic frontier model, Technical Efficiency

1. Introduction

The relationship between environmental degradation and economic growth is one of the main topics of the recent political and economic debate. Several studies have analyzed this relationship because of the increasing awareness on environmental issues.

Since the seminal paper of Grossman and Krueger (1991) on the potential environmental impacts of NAFTA, the work of Shafik and Bandyopadhyay (1992), which provided the backbone for the 1992 World Development Report, and that of Panayotou (1993) for the International Labour Organization, the environmental Kuznets curve (EKC) hypothesis has generated extraordinary research enthusiasm. The EKC hypothesis is based on the existence of an inverted U–shaped relationship between pollution and economic growth. This implies that environmental degradation increases when per capita income is relative low and decreases once a threshold level of per capita income is reached.

The theoretical and empirical literature on pollution and economic growth has supported the existence of an inverted U-shaped curve for some pollutant such as waste, water discharge, sulphur dioxide emissions, carbon monoxide emissions and suspended particles. However for global pollutant such as carbon dioxide (CO_2), it is not clear whether or not exits an EKC. While some papers find a linear relationship between CO_2 emissions and per capita GDP (Shafik and Bandyopadhyay, 1992; Roca et al., 2001; York et al., 2003; Azomahou et al., 2006), others show an inverted U-shaped curve but with a very high level of the turning point (Cole et al., 1997, Agras and Chapman, 1999, Galeotti and Lanza, 1999, Heil and Selden, 2001, Cole, 2004 and Galeotti et al., 2006).

In this paper we want to investigate the CO_2-GDP relationship using a stochastic frontier approach (SFA). We choose to use CO_2 emissions as pollutant certainly because of the great availability of data but also considering the global negative effect connected to these kind of emissions and the rich debate going on in the economic literature.

The aim of this paper is to put emphasis on the relationship between the environmental Kuznets Curve Literature and the Economic Growth Theories as underlined by Brock and Taylor (2011). Differently from them, our production function incorporate directly as input the CO_2 emissions, as in Koop (1998). Our idea is to analyse the best practice production function and its components. In doing so we follow the previous work of Koop (1998) where it is specified a structural model. In the EKC literature, the model estimated can be considered as a reduced form of a theoretical model not well defined. Instead, having in mind the results of Brock and Taylor (2011), we develop an empirical model with which we can decompose the output growth into its different components or inputs such as capital, labour, technical progress and pollution emissions.

We are aware of both the risk of misspecification of the model and the rigidity of some assumptions which are necessary to estimate a production function using the stochastic frontier approach. However, we consider that the benefits of understanding better the growth process and its effects on the environment certainly go beyond the costs deriving from the limitations of the empirical model choosen.

In our analysis we introduce as input one measure of the environmental “bads”: CO_2 emissions. In other words, we want to analyse the contribution of this input to total output growth. However, the empirical results are controlled by other important variables that can influence the main inputs (capital, labour and technological progress in abetment). The efficient frontier estimated allows us to consider inefficient a country that both emits more CO_2 than necessary in the production process and uses more capital and labour than the best practice.

The remaining of the paper is organized as follows. Section 2 reviews the background literature of the relationship between environment degradation and income. Section 3 describes the empirical model used to estimate output growth explicitly considering environment. Section 4 reviews the data and presents our empirical findings while section 5 contains some concluding remarks and future development of this work.

2. Background Literature

The Environmental Kuznets Curve (EKC) literature analyses the existence of an inverted U-shaped relationship between per capita GDP and measures of environmental degradation (Panayotou, 1993 and 2000; Grossman and Krueger, 1991 and 1995; Selden and Song, 1994 and 1995; Lopez, 1994; Holtz-Eakin and Selden 1992; Shafik and Bandyopadhyay, 1992; Hettige, Lucas and Wheeler, 1992, Koop, 1998; Copeland and Taylor, 2004). In several surveys, such as Borghesi (1999); Stagl (1999); Panayotou (2000); Yandle et al. (2004) and Dinda (2004), the EKC results support the existance of an inverted U–shaped curve according to which the environmental degradation at first increases at low levels of income, but then decreases when income improves.

The studies have confirmed that several air pollutants in urban areas follow an inverted U–shaped relationship while per capita national emissions such as CO_2 appear to be monotonic in income even if changes in technology can lead to reductions in pollution over time (Stern, 2004a). However, Auci and Becchetti (2006) have found evidence in favour of a theoretically funded "adjusted EKC hypothesis" in which the impact of per capita GDP on CO_2 emissions is evaluated conditionally to the effects of the industry mix and of the energy-supply infrastructure, even if the shape of the GDP–CO_2 relationship appears quite sensitive to changes in the estimation period.

These papers have studied the relationship between economic growth and the environment through an empirical point of view. According to Koop (1998), these analyses are based on a simple reduced–form function that is linear in parameters but not in variables. In our paper, we focus on the production process. In particular, we put our attention inside the black–box analysing the process which converts inputs and negative by–products such as pollution emissions into outputs. In fact, the improvement of the environment can be obtained by the transformation of this production process into a more efficient and more "green" one.

Several studies have put emphasis on the need of a trasformation of the production process into a production structure that could be more eco–friendly. The literature on productivity measurement with undesiderable outputs such as pollution emission has been started by Pittman (1983). As Pittman explains, reducing the undesirable output requires the diversion of inputs to pollution abatement or the restriction of desirable output. However, Pittman's method requires shadow prices for the undesirable output. On the same strand of literature, other authors (Fare et al., 1986, 1989b, Fare et al., 1989a and Fare et al., 1994b) have developed this approach based on the assumption that pollutants are not freely disposable, that is, some productive resources have to be given up in order to reduce the level of pollutants. They have used the distance function approach, avoiding the need for shadow prices.

Our paper follows this literature but in particular focuses on the recent development of this approach carried on by Koop (1998), Zaim and Taskin (2000a and 2000b) and Stern (2004b). The first two studies adopted a similar global production frontier but in Koop (1998) carbon emissions are treated as inputs, while in Zaim and Taskin (2000a and 2000b) the pollutant is considered as an undesiderable output. Even Stern (2004b)'s study measures the environmental efficiency and technological change using a production frontier method with the Kalman filter to model the state of abatement technology in a panel of countries over time using as pollutant sulfur dioxide emissions.

Following these authors, our paper estimates a production function for the whole world countries, and similarly to Koop (1998) we consider pollution emissions as input of a Cobb–Douglas production function. This approach allows to discriminate countries on the behalf of technology efficiency. Some countries belong to the production frontier and can be considered as “the best practice”, while others are behind the frontier because they use a technology that is less efficient than the best practice.

This analysis can be supported by the recent study of Brock and Taylor (2011), where they develop a theoretical green growth model based on the Solow (1956) growth model. In their analysis, the authors consider intimately related the EKC results with the economic growth theory. In particular, incorporating technological progress in abatement in the Solow model, they establish that the EKC is a necessary by product of convergence to a sustainable growth path.

Thus, having in mind this theoretical green Solow model of Brock and Taylor (2011) and the empirical model of Koop (1998), we want to measure technical inefficiency between countries. In this case the inefficiency obtained is not only a technical inefficiency but also an environmental inefficiency due to the link between technological progress, output growth and pollution. In fact, one of the results of Brock and Taylor (2011) is that “technological progress in abetment must exceed growth in aggregate output in order for pollution to fall and the environment to improve”.

3. The Empirical Model

The neoclassical paradigm in economics assumes that production is always efficient. However, it is quite unrealistic that two countries – even if identical – can produce a similar output with the same costs and profits. In other words, the difference between two countries can be explained through the analysis of efficiency and some unforeseen exogenous shocks, as described by Desli et al. (2002).

A simple OLS regression is not sufficient to estimate the relationship between output and inputs. In fact it has several limits, such as it does not discriminate between rent extraction and productive efficiency and does not simultaneously take into account distances from the efficiency frontier for a given production function.

To test whether CO_2 emissions and standards inputs affect productive efficiency at the country level, we have estimated country production functions using the stochastic frontier approach

(SFA)[1]. This methodology was developed independently by Aigner et al., (1977) and Meeusen and van den Broeck (1977). This approach allows to distinguish between production inputs and efficiency/inefficiency factors and to disentangle distances from the efficient frontier between those due to systematic components and those due to noise. This parametric approach is preferred to nonparametric ones since it avoids that outliers are considered as very efficient countries (Signorini, 2000).

The main idea is that the SFA, which represents the maximum output level for a given input set, is assumed to be stochastic in order to capture exogenous shocks beyond the control of countries.

Since all countries are not able to produce the same frontier output, an additional error term is introduced to represent technical inefficiency that, in turn, is in the control of countries[2]. After these early studies, the SFA methodology has been extended in many directions using both cross-sectional and panel data. The availability of panel data allows to study the behaviour of technical inefficiency over time. Among others, Pitt and Lee (1981), Schmidt and Sickles (1984) Kumbhakar (1987) and Battese et al. (1989) treated technical inefficiency as time invariant while for example Cornwell et al., (1990), Kumbhakar (1990), Battese and Coelli (1992) and Lee and Schmidt (1993) allowed technical inefficiency to vary over time even if they modelled efficiency as a systematic function of time.

The model used in our estimation is based on the Battese and Coelli (1992) – from now on BC – specification. They propose a stochastic frontier production function not only for balanced but also for unbalanced panel data as is our world country dataset which will be described in section 4. In this model, country effects are assumed to be distributed as truncated normal random variables which can vary systematically with time.

The BC model is specified as follows:

(1) $$\ln y = \ln f(x_i;\beta) + v_i - u_i$$

(2) $$u_i = u_i \exp\left(-\eta(t - T)\right)$$

[1] A number of comprehensive reviews of this literature is now available. See for example Forsund et al. (1980), Schmidt (1986), Bauer (1990), Greene (1993) and Coelli et al. (1998).

[2] We follow the Farrel, M.J. (1957) measure of firm's efficiency consisting in two components: technical and allocative. The former reflects the ability of a firm to obtain maximal output from a given set of inputs while the latter reflects the ability of a firm to use the inputs in optimal proportions given their respective prices. These considerations are obviously true also at the country level considering that the aggregate output comes from the sum of national producers.

where random noise in the production function is introduced through the error component v_i which is i.i.d as N(0, σ_v^2) and where the second independent error component, which captures the effects of technical inefficiency, depends on time trend and is a non–negative random variable which is iid as truncations at zero of the N(μ, σ_u^2) distribution.

By combining (1) and (2) we obtain the single stage production frontier model:

$$\ln y = \ln f(x_i;\beta) + v_i - u_i \exp\left(-\eta(t-T)\right) \tag{3}$$

Assuming that the two components are uncorrelated, the parameters can be estimated using the maximum likelihood estimator.

The simultaneous maximum likelihood estimation of the two equation system is expressed in terms of the variance parameters $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \left(\sigma_v^2 + \sigma_u^2\right)$, to provide asymptotically efficient estimates[3]. Hence, it is clear that the test on the significance of the parameter γ is a test on the significance of the stochastic frontier specification (the acceptance of the null hypothesis that the true value of the parameter equals zero implies that σ_u^2, the non random component of the production function residual, is zero).

The technical efficiency of the *i-th* firm in the *t-th* time period is given by:

$$TE_i = e^{(-u_i)} = e^{(u_i \exp(-\eta(t-T)))} \tag{4}$$

Within this model several other models are nested. In fact, if we set η as zero, then we obtain the time – invariant model as described in Battese et al. (1989). In addition, if μ is equal to zero, the SFA model becomes the "model one" of Pitt and Lee (1981). Instead if T is equal to 1 then we return to the original cross – sectional, half–normal formulation of Aigner et al. (1977).

3.1 Our methodology

We adopt the 1992 Battese and Coelli specification and estimate a model both as time–invariant and as time-varying decay. We perform our estimations using a 28–year panel data above more or

[3] The log-likelihood function and the derivatives are presented in the appendix of Battese and Coelli (1993) and Battese and Corra (1977).

less all the world countries. In both specifications we reject the null hypothesis of the insignificance of the non random component of the production function residual.

By assuming that the production function takes the log - linear Cobb-Douglas form, our stochastic frontier production model is specified as follows in the first two column of the results table (table 2):

$$\text{(5)} \quad \ln(Y/L)_{it} = \alpha_0 + \alpha_1 \ln(K/L)_{it} + \alpha_2 \ln(C/L) + \sum_{j=1}^{m-1} \beta_j \ln(K/L)_{it} * HDI_j + v_{it} - u_{it}$$

and as follows in the last two columns of the same table:

$$\text{(5)} \quad \begin{aligned} \ln(Y/L)_{it} &= \alpha_0 + \alpha_1 \ln(K/L)_{it} + \alpha_2 \ln(C/L) + \\ &+ \sum_{j=1}^{m-1} \beta_j \ln(K/L)_{it} * HDI_j + agri\_land + v_{it} - u_{it} \end{aligned}$$

where the dependent variable is the value of output of the i^{th} country at time t (i=1,...,N; t=1,...,T), divided by a scale variable (the total labour force) in order to remove potential problems of heteroskedasticity, multicollinearity and output measurement (Hay-Liu, 1997), *K/L* is the capital stock per worker and *C/L* is the CO_2 emission per worker (details on variable calculations are reported in the Appendix).

To take into account the quality of human capital and its effect on production function we add *m-1* dummies accounting for human development using the Human Development Indicator multiplied by the capital stock per worker. To these variables we add as control variable the measure of agriculture land used inside a country. In this way we can estimate the importance of industry and service sector with respect to the primary sector in the "building" of aggregate income or output.

4. Data and Estimation Results

The data source for our estimations is the World Bank WDI Database. The output and capital variables are measures of GDP and Fixed Capital Formation (in constant 2000 U.S. dollars). Labour is represented by the total labour force and CO_2 represent total emissions of Carbon Dioxide[4]. The adjustment for considering agricultural economies is represented by the amount of agricultural land of each country. Geographical heterogeneity has been taken into account referring to the Human Development Index[5]. Further details concerning the construction of this data are provided in the appendix.

From the overall sample, we select countries for which relevant information for our analysis are available. Starting from a set of 213 countries over the 1960-2009 period we end up with a subset of 151 countries over the period 1980 – 2007. This means estimate stochastic frontiers an unbalanced panel of 151 observations during 28 years.

Table 1 reports descriptive statistics for output, capital, labour and total emissions for the overall panel and for subsets of countries divided considering the value of the Human Development Index.

In particular HD1 represents the group of countries Very High Human Development, HDI2 countries with High Human Development, HDI3 countries with Medium Human Development and HDI4 countries with Low Human Development. This decreasing in the level of development is clearly represented by the decreasing of output. Looking at emissions we can see the huge amount of Carbon Dioxide produced by countries belonging to the HDI1 group.

[4] Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. Source: Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States.

[5] Human Development Report http://hdr.undp.org/en/statistics/

Table 1: Descriptive Statistics

		GDP	FK	LF	CO_2
ALL	mean	187	48.4	16	146805.8
	median	11.2	3.43	3.201576	14890.77
	sd	802	179	62.3	544474.8
	min	0.101	0.0159	0.03134267	7.328
	max	11500	2160	771	6533018
	obs	3931	3109	4228	4146
		GDP	**FK**	**LF**	**CO_2**
HDI1	mean	614	139	12.8	313937.1
	median	131	32	3.97895	59726.86
	sd	1520	312	24.6	859278.6
	min	3.38	0.802	0.1279267	1546.208
	max	11500	2160	157	5836474
	obs	974	872	1008	997
		GDP	**FK**	**LF**	**CO_2**
HDI2	mean	78.8	17.7	9.889921	132762.9
	median	18.6	4.5	3.371712	28894.3
	sd	136	29.1	16.9	318291.1
	min	0.101	0.0278	0.03134267	40.304
	max	816	218	97.9	2548101
	obs	945	759	1064	1064
		GDP	**FK**	**LF**	**CO_2**
HDI3	mean	57.3	20	34.5	144941.8
	median	6.53	1.96	2.16598	6641
	sd	191	75.5	118	571035.7
	min	0.183	0.0263	0.045195	7.328
	max	2460	901	771	6533018
	obs	967	780	1064	1032
		GDP	**FK**	**LF**	**CO_2**
HDI4	mean	5.5	1.02	6.937667	4579.186
	median	2.58	0.511	3.446713	1260.416
	sd	9.24	1.82	10.6	11762.77
	min	0.115	0.0159	0.1194679	47.632
	max	70	19	75.1	110370.7
	obs	1045	698	1092	1053

GDP and FK (fixed capital) are constant 2000 US$ and are expressed in billions; LF is Total Labour Force and is expressed in millions; CO_2 is Total Emissions of Carbon dioxide and is expressed in kt (kilotonnes).

Table 2 reports the results of the Stochastic Frontiers estimations. The Efficient Frontier has been estimated using both the Time-invariant inefficiency model (1 and 3) than the Time-varying decay inefficiency model (2 and 4), as described in section 3. The (3) and (4) specification include a correction for the prevalence of agriculture in a certain economy.

Table 2: Inefficiency models

		(1)	(2)	(3)	(4)
Const	α_0	7.453	7.600	7.436	7.776
		(0.101)**	(0.070)**	(0.193)**	(0.129)**
K/L	α_1	0.210	0.165	0.213	0.156
		(0.011)**	(0.008)**	(0.010)**	(0.008)**
C/L	α_2	0.128	0.129	0.119	0.112
		(0.007)**	(0.007)**	(0.008)**	(0.007)**
K/L*HDI1	β_1	0.338	0.337	0.327	0.329
		(0.015)**	(0.008)**	(0.013)**	(0.008)**
K/L*HDI2	β_2	0.164	0.187	0.180	0.206
		(0.013)**	(0.006)**	(0.010)**	(0.007)**
K/L*HDI3	β_3	0.175	0.184	0.169	0.180
		(0.014)**	(0.010)**	(0.013)**	(0.010)**
Agr	α_3			-0.013	-0.025
				(0.014)	(0.009)**
Observations		3057	3057	2937	2937
Number of cross-sections		144	144	143	143
Wald chi2		6200.25	11192.97	6880.08	12089.86
Log likelihood		1875.4565	2127.3593	1878.7207	2184.8257

Standard errors in parentheses
* significant at 5%; ** significant at 1%

Dep. Var is the log of Y/L (GDP/total labour force); K/L is the log of gross fixed capital formation/total labour force; C/L is the log of total CO_2 emissions/total labour force; HDI1, HD2,HDI3 are dummies that account for HDI as defined in Appendix. Agr is agricoltural land expressed in sq. km.

The estimates of all the four specifications of the frontier functions are clearly significant. As shown in column 3 and 4 the correction for countries mostly agricultural does not change the overall results. The coefficients β_1, β_2, β_3 describe how more developed countries contribute better to the overall efficiency. The clearly positive and strong coefficients of CO_2 emissions highlight how these emissions contribute to growth. Our estimations seems to find a positive linear relationship between per capita CO_2 and per capita GDP, as several studies have already underlined.

Overall considered the results of our econometric models plot a picture in which countries do not pay too much attention at the environment. It seems that the EKC does not exist or that most of the countries still lie on the increasing part of the relation itself.

In order to deepen these aspects we estimate technical efficiencies of each observation contained in our sample, and rank countries according to their level of efficiency (Becchetti and Castelli, 2005). Table 3 reports the results. The ranking have been calculated for each of the 4 models estimated.

Table 3: Country ranking according to technical efficiency

Country	(1)	(2)	(3)	(4)	Country	(1)	(2)	(3)	(4)	Country	(1)	(2)	(3)	(4)
China	1	2	1	7	Ukraine	52	16	47	12	Albania	103	47	95	35
India	2	10	2	13	Egypt, Arab Rep.	53	73	43	71	Sudan	104	123	108	128
Hungary	3	17	3	21	Sweden	54	99	61	108	Chad	105	88	103	79
Korea, Rep.	4	20	4	26	Slovak Republic	55	12	41	16	Latvia	106	109	104	90
Tajikistan	5	1	21	1	Norway	56	101	54	106	Chile	107	124	100	122
Portugal	6	32	7	36	Switzerland	57	102	59	109	Brazil	108	125	102	127
Cyprus	7	33	5	34	Slovenia	58	31	67	33	Congo, Dem. Rep.	109	39	107	38
Estonia	8	3	19	5	Armenia	59	19	60	15	Papua New Guinea	110	133	109	129
Indonesia	9	23	8	29	Burkina Faso	60	54	46	48	Panama	111	131	105	123
Malawi	10	27	6	25	Paraguay	61	83	64	87	Costa Rica	112	132	106	124
Spain	11	38	12	62	Vietnam	62	6	50	4	Venezuela, RB	113	134	110	131
Pakistan	12	28	10	32	Guinea-Bissau	63	36	49	31	Turkey	114	128	111	125
Sri Lanka	13	30	9	30	Belarus	64	22	66	20	Namibia	115	130	119	134
Greece	14	40	13	59	Uganda	65	75	58	63	Maldives	116	106	114	91
Ethiopia	15	26	73	23	Azerbaijan	66	24	57	17	Lithuania	117	112	112	99
New Zealand	16	43	14	61	Kazakhstan	67	25	70	27	Cote d'Ivoire	118	138	121	138
Australia	17	46	15	80	Cambodia	68	14	55	11	Mexico	119	136	116	135
Thailand	18	34	11	40	Togo	69	82	63	68	Trinidad and Tobago	120	126	113	112
Ireland	19	61	20	74	Bangladesh	70	91	65	83	Cameroon	121	140	123	140
Czech Republic	20	11	38	14	Tunisia	71	85	51	65	Central African Republic	122	95	120	82
Canada	21	63	30	89	Algeria	72	89	56	76	Croatia	123	127	118	120
Hong Kong SAR, China	22	65	146	146	Cape Verde	73	68	69	53	Mauritania	124	110	122	110
Finland	23	64	22	75	Madagascar	74	81	72	73	Yemen, Rep.	125	137	124	136
Kyrgyz Republic	24	4	31	3	Botswana	75	104	78	111	Argentina	126	141	125	141
Nicaragua	25	41	16	45	Jordan	76	97	62	70	Mongolia	127	5	126	9
Austria	26	69	27	84	Mali	77	105	75	101	Turkmenistan	128	8	127	10
Netherlands	27	72	32	85	Gambia, The	78	98	74	81	Djibouti	129	144	139	142
Italy	28	74	34	93	Russian Federation	79	37	80	43	Singapore	130	45	129	39
Syrian Arab Republic	29	51	28	60	Germany	80	76	83	94	Bahrain	131	50	131	44
Poland	30	15	24	19	Malaysia	81	107	71	92	Burundi	132	29	130	24
Belgium	31	79	115	96	Guatemala	82	113	85	113	Sierra Leone	133	49	132	41
Philippines	32	52	29	56	Peru	83	108	76	95	Rwanda	134	60	133	50
Mozambique	33	48	23	47	Dominican Republic	84	115	89	115	Congo, Rep.	135	67	135	66
Swaziland	34	56	26	54	Romania	85	58	79	49	Nepal	136	66	134	58
Japan	35	86	37	100	Zambia	86	116	88	114	Equatorial Guinea	137	84	136	77
Bulgaria	36	44	17	37	Guyana	87	21	82	22	Uruguay	138	142	128	139
Uzbekistan	37	13	48	18	Kenya	88	117	90	116	Niger	139	80	138	72
France	38	87	45	104	Gabon	89	121	97	126	Tonga	140	93	137	57
Ghana	39	57	33	55	Macedonia, FYR	90	62	86	46	Angola	141	129	140	133
Moldova	40	9	35	6	Senegal	91	119	91	118	Saudi Arabia	142	143	142	143
Bolivia	41	59	36	64	Guinea	92	103	87	97	Solomon Islands	143	135	141	130
Iceland	42	90	42	98	Comoros	93	118	81	105	Libya	144	139	143	137
Ecuador	43	53	18	42	Mauritius	94	114	77	88	Colombia	145	145	144	144
Iran, Islamic Rep.	44	55	25	51	El Salvador	95	120	98	121	Haiti	146	146	145	145
Georgia	45	18	40	8	South Africa	96	122	101	132	Jamaica	147	147	147	147
Denmark	46	94	52	103	United Arab Emirates	97	42	94	52	Lesotho	148	148	148	148
United Kingdom	47	92	53	107	Benin	98	111	92	102	Liberia	149	149	149	149
Morocco	48	71	44	78	Tanzania	99	77	93	69	Nigeria	150	150	150	150
Honduras	49	70	39	67	Bosnia and Herzegovina	100	35	84	28	Timor-Leste	151	151	151	151
Luxembourg	50	100	117	117	Lao PDR	101	7	96	2					
United States	51	96	68	119	Israel	102	78	99	86					

In table 3 countries have been ordered according to the ranking of the technical efficiencies estimated using model (1) which is the Time-invariant inefficiency model with no correction for agriculture. Columns (2), (3) and (4) report respectively the ranking based on the technical efficiencies estimated using the other three specifications.

The results show that China and India are placed more or less at the top of the classification in all four estimations. This seems to suggest that even if these frontiers could be defined as efficient in terms of productivity, they seems not to be the same in terms of attention to the Environment. In this sense, we see that pollution increases production and consequently we can classify them as "environmentally inefficient frontiers".

As a counter evidence of this, we can focus our attention on the position of Sweden which is one of the most sensitive country to environmental degradation. Sweden is always at the bottom of these classifications. Thus, the more a country is distant from the production frontier the more is the awareness about environment and its negative consequences.

In other words, world countries tend to be interested mainly in reaching a certain level of welfare without considering the degradation of the environment. This conclusion surely holds if we estimate the production function using the model with time-invariant technical efficiency. Using the model with time-variant technical efficiency instead, the developed countries tend to be more aware of the "bad" by-product of their industrialization. In fact, the position of these countries tend to be more distant from the "inefficient frontier" especially because they are changing their environmental policy since the environmental standards are becoming more tough and stringent.

5. Concluding Remarks

In this paper we have considered the relationship between the EKC and Growth Theory by explicitly incorporating CO_2 emissions as input in countries production functions estimated using Stochastic Frontiers. The idea has been that of understanding the contribution of CO_2 emissions to growth, looking at possible shiftings and/or movements towards or away of the efficient frontier. In doing so, we have explicitly taken into account country heterogeneity in the world using the Human Development Index as an indicator of development.

We find evidence of the positive contribution of CO_2 to growth but also of poor care of environment protection by most of countries. It seems that the EKC does not exist or that most of the countries still lie on the increasing part of the relation itself. This means that maybe the eco-friendly approach to growth still lag behind.

These first results seems to be promising for future development. In particular we want to enlarge the panel both in terms of countries than time series. Secondly we will perform the estimation of the Stochastic Frontiers using Frontier 4.1 in order to compare the different techniques of estimation with the one used here (Battese and Coelli 1995 vs Battese and Coelli 1992). In doing this we will add new factors that we think could be determinants of efficiency such as Education, Corruption, Technical Change etc.

APPENDIX

Output (Y): GDP at constant 2000 US dollars

Capital (K): Gross Fixed Capital Formation at constant 2000 US dollars

Labour (L): Total Labour Force

CO_2 (C): Total Carbon Dioxide (CO_2) emissions expressed in kt

Agricoltural Land (Ag): total agricultural land of each country expressed in sq km

Countries:

Albania, Algeria, Angola, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Belarus, Belgium, Benin, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Dem. Rep., Congo, Rep., Costa Rica, Cote d'Ivoire, Croatia, Cyprus, Czech Republic, Denmark, Djibouti, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Estonia, Ethiopia, Finland, France, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hong Kong SAR, Hungary, Iceland, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Rep. of Korea, Kyrgyz Republic, Lao PDR, Latvia, Lesotho, Liberia, Libya, Lithuania, Luxembourg, Macedonia FYR, Madagascar, Malawi, Malaysia, Maldives, Mali, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Pakistan, Panama, Papua New Guinea, Paraguay, Perù, Philippines, Poland, Portugal, Romania, Russian Federation, Rwanda, Saudi Arabia, Senegal, Sierra Leone, Singapore, Slovak Republic, Slovenia, Solomon Islands, South Africa, Spain, Sri Lanka, Sudan, Swaziland, Sweden, Switzerland, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen, Zambia

Sample countries have been grouped according to the HDR classification:

HDI_1(dummy): Very High Human Development: Australia, Austria, Bahrain, Belgium, Canada, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong SAR, Hungary, Iceland, Ireland, Israel, Italy, Japan, Rep. of Korea, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Arab Emirates, United Kingdom, United States.

HDI_2(dummy): High Human Development: Albania, Algeria, Argentina, , Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Brazil, Bulgaria, Chile, Colombia, Costa Rica, Croatia, Ecuador, Georgia, Iran, Jamaica, Jordan, Kazakhstan, Latvia, Lithuania, Macedonia FYR, Malaysia, Mauritius, Mexico, Panama, Peru, Romania, Russian Federation, Saudi Arabia, Tonga, Trinidad and Tobago, Tunisia, Turkey, Ukraine, Uruguay, Venezuela.

HDI_3(dummy): Medium Human Development: Bolivia, Botswana, Cambodia, Cape Verde, China, Rep. of Congo, Dominican Republic, Egypt, El Salvador, Equatorial Guinea, Gabon, Guatemala, Guyana, Honduras, India, Indonesia, Kyrgyz Republic, Lao PDR, Maldives, Moldova, Mongolia, Morocco, Namibia, Nicaragua, Pakistan, Paraguay, Philippines, Solomon Islands, South Africa, Sri Lanka, Swaziland, Syrian Arab Republic, Tajikistan, Thailand, Timor-Leste, Turkmenistan, Uzbekistan, Vietnam.

HDI_4(dummy): Low Human Development: Angola, Bangladesh, Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Comoros, Dem. Rep. of Congo, Cote d'Ivoire, Djibouti, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Haiti, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Nepal, Niger, Nigeria, Papua New Guinea, Rwanda, Senegal, Sierra Leone, Sudan, Tanzania, Togo, Uganda, Yemen, Zambia.

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