Measurement of Environmental Efficiency and Productivity: A Cross Country Analysis

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Abstract

This paper measures environmental efficiency (EE) and environmental productivity (EP) and analyses differences in these across countries. It explores the macroeconomic factors that could explain these differences and whether these differences can be explained by income levels and by the degree of openness in these countries. The EE index is found to be almost steady over the period 1971-92 for the annex-I countries, while its value is declining for non-annex-I countries over this period. The EP index increased over this period in both groups of countries. In the annex-I countries, EE exhibits an inverted 'U' shape with respect to per capita income while it is 'U' shaped for the non-annex-I countries. This study also finds that while the EP index increases with income in annex-I countries it is decreasing in the non-annex-I countries. The degree of openness has a significant negative impact on EE and EP in both groups of countries.

Key-words: Environmental efficiency, Environmental productivity, Distance function, Per capita income, Openness.

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JEL Classification: C61, D24, F43, O12, P24, Q25, Q32

Acknowledgement

The authors wish to thank Professor B. N. Goldar for his valuable comments. However, the usual disclaimer applies.

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Introduction

There is concern about carbon emissions due to its potential to cause global warming. At the same time, concerns about the costs of abating carbon emissions have made countries hesitant about reducing these emissions. These costs are likely to vary across countries due to differences in technology, differences in the mix of energy, capital, and labour used by these countries and differences in the productivity of those inputs. This paper seeks to estimate these costs of abatement, measured using the concept of environmental efficiency (EE), and environmental productivity (EP) and to analyse differences in these across countries. It then explores the macro-economic factors that could explain these differences and in particular whether these differences can be explained by income levels in these countries.

We measure EE and EP for a set of 42 countries for the period 1971-1992 using the distance function approach. These countries include twenty-one annex-I countries and twenty-one non-annex-I countries.[1] The distance function incorporates both the desirable output (Gross Domestic Product (GDP)) and undesirable output (CO_2) to provide a measure of "how far" each country's input vector is from the best practice input frontier, given an output vector. These measures of efficiency and productivity are obtained under alternative assumptions about the disposability of CO_2, that is, it could be strongly disposable or weakly disposable. Strong disposability implies that a country can reduce CO_2 emissions without reducing GDP or incurring any abatement costs. On the other hand, weak disposability implies that to reduce CO_2 emissions, a country has to divert its resources from the production of good outputs.

We measure technical efficiency under the assumption of weak disposability to determine the potential that a country has for reducing CO_2 emissions while keeping good outputs constant through efficiency gains. We compare the technical efficiency of a country under alternative assumptions regarding disposability of CO_2 emissions to obtain a measure of its EE. The latter measures the extent to which the ability of a country to increase its efficiency and reduce its inputs would be constrained by the need to reduce CO_2.

We examine the trends in productivity for individual countries under the assumption that CO_2 emissions are weakly disposable and compare these estimates with the conventional measures of productivity that ignore the generation of these emissions. The ratio of total factor productivity (TFP) under weak to strong disposability provides the measure of EP. Productivity is conventionally measured using index numbers, which requires data on prices of all outputs and inputs. The distance function approach can help overcome the problems associated with the index number approach since it requires data only on quantities of inputs, outputs and pollutants.

Other studies estimating the EE of countries include Zaim and Taskin (2000), Taskin and Zaim (2001), and Zofio and Prieto (2001). These studies use non-parametric methods to estimate the EE. While Zaim and Taskin (2000) and Taskin and Zaim (2001) focus on examining the existence of an environmental Kuznets curve (EKC) relationship for EE, Zofio and Prieto (2001) estimate the opportunity costs of reducing CO_2 by increasing efficiency. Taskin and Zaim (2001) examine the impact of international trade also on EE for a sample of 49 developed and developing countries. However, Zaim and Taskin (2000), and Zofio and Prieto (2001) used a sample of OECD countries only.

An important issue in efficiency and productivity studies is the credibility of the assumption that all producing units can actually reach the same best practice production frontier. In the present study, in contrast to Taskin and Zaim (2001), we assume that there are two different best practice frontiers, one for annex-I countries and one for non-annex-I countries because non-annex-I countries may not have access to the same technologies that are available to annex-I countries. Due to lack of availability of longer time series of data for the entire sample of countries considered here, our study is limited to the 1971-92 period only.

There are several studies on the measurement of efficiency and productivity changes in industries, which produce good and bad outputs simultaneously during the production process. Some of these studies have treated the bad outputs as inputs,[2] while others have treated them as a synthetic output such as pollution abatement (e.g. Gollop and Robert, 1983). Murty and Russell (2002) have pointed out that the treatment of bad outputs as inputs is not consistent with the materials balance approach. The approach adopted by Gollop and Robert to treat the reduction in bad output as good output creates a different non-linear transformation of the original variable in the absence of base constrained emission rates (Atkinson and Dorfman, 2002). To overcome this problem, Pittman (1983) proposed that good and bad outputs should be treated non-symmetrically.

Chung *et. al*., (1997) used the directional distance function to calculate production relationships involving good and bad outputs while treating them asymmetrically. In directional distance functions, finding appropriate directional vector is a critical task for acceptable estimates of efficiency and productivity (Lee *et. al.,* 2002). In our data set (Table 1), there is no clear shift in output mix in favour of either of the outputs. Moreover, there are possibilities of infeasible solutions.[3] Therefore, following Atkinson and Dorfman (2002), input distance function is used as an analytical tool in the present study to obtain a radial measure of efficiency. This function is less restrictive in the sense that it is not treating the bad outputs, either inputs or pollution abatement as good output, rather it treats the bad outputs as an 'exogenous' technology shifter with countries/firms that can use lesser quantities of inputs for producing a given level of outputs as being more technically efficient.

There is a large empirical literature[4] examining the EKC relationship and seeking to establish an inverted U-type relationship between the level of emissions and per capita income levels. This literature shows that there is a statistical reduced form relationship between emissions and per capita income but does not explain the process that generates this relationship. A few studies[5] recognise that transformation in the production processes that leads to improvement in environmental quality pertain to production frontier approach but these studies have only examined the pattern of EE across countries and not of EP. This paper contributes to this literature by examining the causes of change not only in the EE index but also in the EP index for annex-I countries and non-annex-I countries. It includes per capita GDP and openness of a country among other explanatory variables to explain differences in EE and EP across countries.

The remainder of the paper is organised as follows: In section II, we discuss the theoretical construction of the paper. The empirical model is presented in section III. Section IV describes and discusses the data used in the study and results. The paper closes in section V with some concluding remarks.

II. Theoretical Construct

Suppose that a country employs a vector of inputs $x \in \Re^{K}_{+}$ to produce a vector of good outputs $y \in \Re^{M}_{+}$, and undesirable outputs $b \in \Re^{N}_{+}$. Let $P(x)$ be the feasible output set for the given input vector x and $L(y, b)$ is the input requirement set for a given output vector (y, b). Now the technology set is defined as:

$$T = \{(y, b, x) \in \Re^{M+N+K}_{+}, (y, b) \in P(x), x \in L(y, b)\} \tag{1}$$

The technology is modeled in alternative ways. The output is strongly or freely disposable if $(y, b) \in P(x)$ and $(y', b') \leq (y, b) \Rightarrow (y', b') \in P(x)$ which implies that if an observed output vector is feasible, then any output vector smaller than that is also feasible. This assumption excludes production processes that generate undesirable outputs that are costly to dispose. For example, concerns about CO_2 and other greenhouse gases imply that these should not be considered to be freely disposable. In such cases bad outputs are considered as being weakly disposable: $(y, b) \in P(x)$ and $0 \leq \theta \leq 1 \Rightarrow (\theta y, \theta b) \in P(x)$. This implies that pollution is costly to dispose and abatement activities would typically divert resources away from the production of desirable outputs and thus lead to lower good output with given inputs.

A functional representation of the technology is provided by Shephard's (1970) input distance function, which also provides a measure of performance or efficiency. The input distance function describes "how far" an input vector is from the boundary of the representative input set, given the fixed output vector. Formally, the input distance function[6] is defined as

$$D_i^t\left(\mathbf{y}^t, \mathbf{b}^{\mathbf{t}}, \mathbf{x}^t\right) = \sup_{\lambda}\{\lambda : \left[\mathbf{x}^t / \lambda, \mathbf{y}^t, \mathbf{b}^{\mathbf{t}}\right] \in T^t\} \tag{2}$$

Equation (2) characterises the input possibility set by the maximum *equi*-proportional contraction of all inputs consistent with the technology set (1).

If one assumes that the efficiency measures over the desirable outputs and inputs are well-defined and behave as expected, the bad outputs can be treated as exogenous shifters of the technology set similar to a time trend or state of technology variable. The merit of this assumption is that it credits (penalises) the countries for reducing (increasing) the level of bad outputs that they produce (Atkinson and Dorfman, 2002). To emphasise the point, the input distance function is now written as:

$$D_i\left\langle \mathbf{y}, \mathbf{x}, t \middle| \mathbf{b} \right\rangle = \sup_{\lambda}\left\{\lambda : \left\langle \mathbf{x}/\lambda, \mathbf{y} \middle| \mathbf{b} \right\rangle \in T\left\langle \mathbf{x}, \mathbf{y}, t \middle| \mathbf{b} \right\rangle\right\} \tag{3}$$

Assuming a single bad output, Atkinson and Dorfman have derived the appropriate monotonocity condition for bad outputs.

Environmental Efficiency (EE)

Following Fare *et. al.*, (1996), we assume that the input distance function is separable in the sense of: $D_i^t(\mathbf{y}^{\mathbf{t}}, \mathbf{b}^{\mathbf{t}}, \mathbf{x}^{\mathbf{t}}) = B(\mathbf{b}^t)\widehat{D}_i^t(\mathbf{y}^{\mathbf{t}}, \mathbf{x}^{\mathbf{t}}),$ where $\widehat{D}_i^t(\mathbf{y}^{\mathbf{t}}, \mathbf{x}^{\mathbf{t}}) = \sup_{\mu}\{\mu : (\mathbf{x}^t / \mu, \mathbf{y}^t) \in \widehat{T}\}$ and $\widehat{T} = \{(\mathbf{y}^{\mathbf{t}}, \mathbf{x}^{\mathbf{t}}) : \mathbf{x}^t$ can produce $\mathbf{y}^t\}$. Here, set $\widehat{T}$ is a technology set restricted to the production of good outputs only without any consideration for undesirable outputs $\mathbf{b}^t$. Therefore, with this assumption one can decompose technical efficiency into the factors that reflect the influence of 'pure' input technical efficiency, $\widehat{D}_i^t(\mathbf{y}^t, \mathbf{x}^t)$ and the effect of undesirable outputs, $B(\mathbf{b}^t)$. Thus, EE is defined as:

$$EE = B(\mathbf{b}^t) = D_i^t(\mathbf{y}^t, \mathbf{b}^t, \mathbf{x}^t) / \widehat{D}_i^t(\mathbf{y}^t, \mathbf{x}^t) \tag{4}$$

EE will take values less than or equal to one. It represents the extent to which a country would be constrained in reducing inputs by its potential to transfer its production process from free disposability to costly disposal of CO_2 emissions. Countries that are less constrained have a lower opportunity cost of transfer in production process and are considered to be more environmentally efficient.

Environmental Productivity (EP)

The Malmquist index and its components efficiency change (EC) and technical change (TC) are defined in terms of the ratios of distance functions. The input-based Malmquist index under strong (MS) and weak (MW) disposability of CO_2 emissions is defined respectively as:

$$MS = \underbrace{\left[\frac{D_i^t(\mathbf{y}^t, \mathbf{x}^t)}{D_i^{t+1}(\mathbf{y}^{t+1}, \mathbf{x}^{t+1})}\right]}_{Efficiency Change} \cdot \underbrace{\left[\frac{D_i^{t+1}(\mathbf{y}^{t+1}, \mathbf{x}^{t+1})}{D_i^t(\mathbf{y}^{t+1}, \mathbf{x}^{t+1})} \frac{D_i^{t+1}(\mathbf{y}^t, \mathbf{x}^t)}{D_i^t(\mathbf{y}^t, \mathbf{x}^t)}\right]^{\frac{1}{2}}}_{Technical Change} \tag{5}$$

$$MW = \underbrace{\left[\frac{D_i^t(\mathbf{y}^t, \mathbf{b}^t, \mathbf{x}^t)}{D_i^{t+1}(\mathbf{y}^{t+1}, \mathbf{b}^{t+1}, \mathbf{x}^{t+1})}\right]}_{Efficiency Change} \cdot \underbrace{\left[\frac{D_i^{t+1}(\mathbf{y}^{t+1}, \mathbf{b}^{t+1}, \mathbf{x}^{t+1})}{D_i^t(\mathbf{y}^{t+1}, \mathbf{b}^{t+1}, \mathbf{x}^{t+1})} \frac{D_i^{t+1}(\mathbf{y}^t, \mathbf{b}^t, \mathbf{x}^t)}{D_i^t(\mathbf{y}^t, \mathbf{b}^t, \mathbf{x}^t)}\right]^{\frac{1}{2}}}_{Technical Change} \tag{6}$$

The first ratio in equations (5) and (6) measures EC under strong and weak disposability of CO_2 emissions respectively. The geometric mean of the two ratios inside the bracket in these equations captures the shift in technology between the two periods. The value of Malmquist index greater (less) than unity indicates the improvement (deterioration) over time in productivity.

Following Managi *et. al.*, (2002), we decompose MW into MS and EP as follows:

$$MW = MS.EP \tag{7}$$

This decomposition can be carried out by computing the values of input distance functions under alternative assumption regarding disposability of CO_2 emissions. Thus, EP is measured as:

$$EP = MW / MS \tag{8}$$

III. Empirical Model

We use the parametric linear programming approach proposed by Aigner and Chu (1968), for estimating the parameters of the distance function. The translog specification that is adopted here for the transformation function corresponds to multi-output/multi-input technology with technical progress defined in the usual form as a trend variable:

$$\ln D_i^t (x^t, y^t, b^t) = \alpha_0 + \sum_{n=1}^{N} \alpha_n x_n^t + \frac{1}{2} \sum_{n=1}^{N} \sum_{n'=1}^{N} \alpha_{nn'} \ln x_n^t \ln x_{n'}^t + \beta_1 \ln y^t + \frac{1}{2} \beta_2 \ln y^t \ln y_{'}^t + \gamma_1 \ln b^t + \frac{1}{2} \gamma_2 \ln b^t \ln b^{'t} + \sum_{n=1}^{N} \delta_n \ln x_n^{'t} \ln y^t + \sum_{n=1}^{N} \eta_n \ln x_n^t \ln b^t + \varphi \ln y^t \ln b^t + \lambda_1 t + \frac{1}{2} \lambda_2 t^2 + \sum_{n=1}^{N} \mu_n \ln x_n^t t + \pi \ln y^t t + \theta \ln b^t t \tag{9}$$

The isoquant of the input set corresponds to: *$\ln D_i^t (x^t, y^t, b^t) = 0$* and the exterior points: *$\ln D_i^t (x^t, y^t, b^t) \geq 0$*. Therefore, this is accomplished by solving the problem, Minimise $\sum_{k=1}^{K}\left\{\ln D_i^t(\mathbf{y}^t,\mathbf{b}^t,\mathbf{x}^t,t)-\ln 1\right\}, k=1,2,.....K.$ (10)

Subject to

(i) $\ln D_i^t(\mathbf{y}^t,\mathbf{b}^t,\mathbf{x}^t,t)\geq 0$

(ii) $\frac{\partial \ln D_i^t(\mathbf{y}^t,\mathbf{b}^t,\mathbf{x}^t,t)}{\partial \ln y^t}\leq 0,$

(iii) $\frac{\partial \ln D_i^t(\mathbf{y}^t,\mathbf{b}^t,\mathbf{x}^t,t)}{\partial \ln b^t}\geq 0,$

(iv) $\frac{\partial \ln D_i^t(\mathbf{y}^t,\mathbf{b}^t,\mathbf{x}^t,t)}{\partial \ln x_n^t}\geq 0, n=1,......., N.$

(v) $\sum_{n=1}^{N}\alpha_n=1, \sum_{n'=1}^{N}\alpha_{nn'}=\sum_{n=1}^{N}\delta_n=\sum_{n=1}^{N}\pi_n=0, n, n'=1,......., N$

(vi) $\alpha_{nn'}=\alpha_{n'n}, n, n'=1,......., N$

where K denote the number of observations. The restriction in (i) ensures that the value of input distance function is greater than or equal to one as the logarithm of this function are restricted to be greater than or equal to zero. Restriction in (ii) enforces the monotonocity condition of non-increasing of input distance function in good outputs, whereas the restrictions in (iii) impose that the input distance function is non-decreasing in bad outputs when they are weakly disposable and the inequality in (iii) changes to equality when the emissions are strongly disposable. Restrictions in (iv) enforce that the input distance function is non-decreasing in inputs. Restriction (v) and (vi) impose the homogeneity and symmetry conditions respectively as required by the theory.

Following Orea (2002), MS and MW are calculated as follows:

$$\ln MS = \left[\ln D_i^t(\mathbf{y}^t, \mathbf{x}^t, t) - \ln D_i^{t+1}(\mathbf{y}^{t+1}, \mathbf{x}^{t+1}, t)\right] - \frac{1}{2}\left[\frac{\partial \ln D_i^{t+1}(\mathbf{y}^{t+1}, \mathbf{x}^{t+1}, t)}{\partial t} + \frac{\partial \ln D_i^t(\mathbf{y}^t, \mathbf{x}^t, t)}{\partial t}\right] \tag{11}$$

$$\ln MW = \left[\ln D_i^t(\mathbf{y}^t, \mathbf{b}^t, \mathbf{x}^t, t) - \ln D_i^{t+1}(\mathbf{y}^{t+1}, \mathbf{b}^{t+1}, \mathbf{x}^{t+1}, t)\right] - \frac{1}{2}\left[\frac{\partial \ln D_i^{t+1}(\mathbf{y}^{t+1}, \mathbf{b}^{t+1}, \mathbf{x}^{t+1}, t)}{\partial t} + \frac{\partial \ln D_i^t(\mathbf{y}^t, \mathbf{b}^t, \mathbf{x}^t, t)}{\partial t}\right] \tag{12}$$

These equations provide a meaningful decomposition of the Malmquist index into EC and TC. The negative sign of the second term transforms technical progress (regress) into positive (negative) value.

IV. Data and Discussion of Results

We obtain data on five variables namely: GDP, CO_2, labour force, capital stock and commercial energy consumption for 42 countries for the period 1971-1992. Out of these five variables the first two variables, GDP and CO_2 are considered as proxies of good and bad outputs respectively, and the remaining three are taken as inputs. Data on the GDP, labour force, and energy consumption are collected from the World Development Indicators (WDI) (World Bank), whereas data on CO_2 are obtained from the website of World Resources Institute[7]. Capital stock[8] data are obtained from the Penn World Tables (Mark 5.6). GDP and capital stock are measured in 1985 US dollars, whereas CO_2 and energy consumption is measured in thousand metric tons. The labour force data is in millions of employees.

The 42 countries[9] included here are those for which capital stock data alongwith other variables are available over the period of 1971-1992. The selection of period is based on the availability of capital data that is taken from Penn World Tables. The descriptive statistics of all the variables used in the study for both of the groups, i.e. annex-I and non-annex-I countries is presented in Table 1. The descriptive statistics brings into focus the contrast in these two groups.

The newly industrialised country Hong Kong registered the highest growth rate of GDP (7.9 per cent) and it also had a high growth rate for CO_2 emissions (6.5 per cent). Thailand experienced the second highest growth rate of GDP of 7.3 per cent but a more rapid rate of growth in the production of CO_2, i.e. 8.3 per cent. The highest growth rate with respect to CO_2 was in the Syrian Arab Republic (9.14 per cent). Overall growth rates reveal that developing countries had higher growth rates in GDP, CO_2 and commercial energy consumption in comparison to the developed countries. Sweden, Luxembourg, France, Belgium, United Kingdom and Denmark registered negative CO_2 growth rates of 2.93, 1.96, 1.71, 1.57, 0.66 and 0.32 per cent respectively. Thus, we observe that during the study period, non-annex-I countries not only had higher growth rates of income and emissions relative to annex-I countries, but there was also a higher degree of variability within this group. The emission intensity of output measured as a ratio of CO_2 emission to GDP was relatively higher in developing countries. However, the per capita GDP, capital, CO_2 emissions and commercial energy consumption were substantially higher in developed countries in comparison to the developing economies.

Estimates of Input Distance Function

In Table 2, the computed parameters for a deterministic distance function for annex-I and non-annex-I countries are presented. The input distance function in equation (13) is estimated with and without including CO_2 for both sets of countries. This allows us to examine the importance of the inclusion of CO_2 emissions in the analysis of efficiency and productivity changes. Both models, when CO_2 is weakly disposable and when it is ignored, yield first order coefficients on inputs that have signs consistent with economic theory. The distance functions satisfy the regulatory conditions on good outputs and convexity on inputs and bad outputs for average values of the explanatory variables.

As described earlier the input distance function serves as an input-based measure of technical efficiency, the average value of this function in both the models at certain points of time are presented in Table 3[10]. We observe that the efficiency scores when CO_2 emissions are ignored are lower in comparison to the situation when this pollutant is weakly disposable. It reveals that the potential to increase the production of desirable output with the given bundle of input would decrease if the disposal of CO_2 emissions was not free.

On average the value of input distance function for non-annex-I countries ranges from 1.011 for Paraguay to 1.153 for Nigeria. This reveals that 1.1 per cent to 15.3 per cent of the conventional inputs could have been saved by improving efficiency and achieving the best practice frontier under the assumption of strong disposability of CO_2 emissions for these countries. For the annex-I countries this figure ranges between 1.002 for Australia, Austria, Belgium, Canada, and France to 1.048 for Luxembourg. Under the weak disposability assumption the average values of input distance function for non-annex-I and annex-I countries are 1.010 and 1.003 respectively.

Environmental Efficiency of Countries

The estimates of EE are presented in Table 3. Results for non-annex-I and annex-I countries show that on average the EE scores are 0.965 and 0.994 respectively. It reveals that on average these groups of countries have an environmentally binding production technology. Under both disposability assumptions, inefficiency in the non-annex-I countries is higher in comparison to annex-I nations. In the non-annex group, countries with larger inefficiency differentials under the strong and weak disposability of CO_2 assumption are Nigeria, Zambia, Peru, Morocco, Kenya, Mexico, and Guatemala. These countries have more environmentally binding production technology than others. On the other hand there is only one country in non-annex-I countries that is free from environmental constraints, i.e., Hong Kong. Among the annex-I countries, there are only three countries that have differential of more than one percent under alternative disposability conditions in the technical efficiency scores, i.e. Luxembourg, Ireland, and New Zealand. We also find that the EE index is almost steady in annex-I countries, while its value is declining in the non-annex-I countries over time (Figure 1).

Countries with different efficiency scores suffer congestion from CO_2 emissions, i.e., if the countries were to reduce emissions they would have to sacrifice their GDP since good and bad outputs cannot be dissociated. Once this inefficiency is translated into loss of desirable output, results show that developing countries like Nigeria, Zambia, Peru, Morocco, Kenya, Mexico, and Guatemala would have to lose more than two percent of their GDP due to congestion of production technology. As a whole, countries in our sample would lose 2.10 per cent of GDP on average due to environmentally binding production technology. The relative output loss due to imposition of costly abatement for non-annex-I countries is higher than the average. Moreover, the gap in the level of EE in annex-I and non-annex-I countries is increasing over time (Figure 1).

The measure of efficiency under weak disposability of CO_2 can alternatively be interpreted as a measure of the existence of potential win-win opportunities. This index shows the potential for a country relative to the best practice frontier. This win-win opportunity is slightly higher for non-annex-I countries than for annex-I countries (Table 3). The technical efficiency under weak disposability of CO_2 is 0.991 for these countries and 0.996 for the annex-I countries. It implies that non-annex-I countries can decrease inputs along with reductions in CO_2 emissions by 0.9 per cent per year while developed countries can decrease inputs and emissions by 0.4 per cent per year.

Determinants of Environmental Efficiency

We now examine the factors that determine the changes in the EE index over time and the differences across countries. It is hypothesised that specific attributes of an individual country contribute to the environmental performance of that country. Using a panel data framework, we examine the relationship between EE and its determinants, by including variables such as GDP per capita, share of industrial output in GDP, capital-labour ratio, energy intensity measured by the use of commercial energy per unit of GDP, population density and openness index. The openness index could be a proxy for institutional and policy framework of a country. The source of data on per capita GDP, share of industrial output, openness index and population density is the WDI.

The equation below specifies a possible form relation between the EE and the variables discussed above.

$$EE_{it} = \beta_{1i} + \beta_2 GDPPC_{it} + \beta_3 (GDPPC)^2_{it} + \beta_4 (GDPPC)^3_{it} +$$
$$\beta_5 INDSHARE_{it} + \beta_6 (INDHSARE)^2_{it} + \beta_7 CAPLAB_{it} + \beta_8 ENGDP_{it}$$
$$+ \beta_9 POPDENS_{it} + \beta_{10} OPEN + \beta_{11} (OPEN)^2 + \varepsilon_{it}$$

where: i is country index; t is time index; ε is the disturbance term such that $\varepsilon \sim N(0, \sigma_\varepsilon)$; GDPPC is GDP per capita; INDSHARE is share of industrial output in GDP; CAPLAB is capital per labour; ENGDP is use of commercial energy per unit of GDP; POPDENS is population density; and OPEN, openness index defined as the ratio of total exports and imports to GDP.

The shape of polynomial shows the relationship between EE and GDP per capita. It is expected that in the initial phases of industrialisation, EE would deteriorate and there should be an improvement once a critical level of industrialisation is reached. This implies a quadratic relationship between EE and share of industrial output in GDP, with first order coefficient to be positive and second order coefficient to be negative. A positive sign is expected for capital per labour variable if capital intensity leads to increase in EE, otherwise it should be negative. A negative sign is expected for ENGDP variable since it can be assumed that higher energy intensity of output leads to decline in EE. With respect to the variable population density sign can be either positive or negative[11]. The openness variable can show both the positive and negative effects of increased volume of trade on the EE. On the negative side it captures the environmentally deteriorating effects that stem from increased volume of trade. On the positive side it captures the environmentally beneficial effects that stem from free trade and easier access to cleaner inputs and technologies. The sign and significance of the openness variable (and its quadratic term) will help to select among the competing hypotheses on environment and international trade.

Table 5 provides the parameters estimates of the regressions for the EE index under alternative specifications. The first three columns of the table report the estimation results for annex-I countries and the last three columns are the parameter estimates of models for non-annex-I countries. A LM test performed on the alternative specifications of the fixed effect models accepts the null hypothesis of a common intercept in favor of the model against country specific intercept terms for both of the groups of countries. Furthermore, the choice between the fixed effect models and the random effect model can be made using the Hausman test. We reject the null hypothesis for annex-I countries which suggests the random effect model is the appropriate specification and but for non-annex-I countries we find the fixed effect specification to be appropriate.

The most apparent outcome in all the specifications of the model is that variable GDP per capita, its quadratic and cubic terms are statistically significant. In the annex-I countries we find that in the initial phases of growth (up to an per capita GDP level of approximately US$ 20,500 according to the random effect model, Figure 2) there is an improvement in EE which is followed by a phase of deterioration and then a further improvement once a critical level of per capita GDP (approximately US$ 40,000, Figure 2) is reached. But in the non-annex-I countries the situation is just opposite. In these countries, we find that in the initial phases of growth (up to an per capita GDP level of approximately US$ 5,500 according to the fixed effect model, Figure 3) there is a decline in EE which is followed by a phase of improvement and then a further decline once a critical level of per capita GDP is reached (approximately US$ 15,000, Figure 3). This implies that in the annex-I countries, the opportunity cost of the transformation of a production process from free to costly disposal of CO_2 emission is becoming smaller after a certain threshold income level. But the non-annex-I countries are far behind in GDP per capita in comparison to their counterpart annex-I countries, and the opportunity costs of transformation in production process are increasing. This helps in explaining the increasing differentials between the annex-I countries and non-annex-I countries in the level of EE index over time (Figure 1).

The share of industrial output in GDP variable exhibits a U-curve type quadratic relationship in annex-I countries. This finding concurs with the findings of Zaim and Taskin (2000). In non-annex-I countries, the linear coefficient is insignificant but the coefficient of the quadratic term is negative and significant at 10 per cent of critical level. This indicates that in the initial phases of industrialisation in these countries EE remains unaffected, but as the process of industrialisation increases, EE starts declining.

Moreover, we find that the coefficient of the variables POPDENS is consistently significant for both the groups, this variable is positively and negatively related to EE in annex-I and non-annex-I countries respectively. The coefficient of the energy intensity variable is negative and statistically significant for both the groups, indicating that the increase in energy intensity leads to decrease in EE. The increase in capital per labour leads to increase in EE in both the groups.

Other variables that we included in the model are the index of openness and its quadratic term. Here we hypothesise that the openness variable also exhibits a U shaped relationship with EE. We find that in the annex-I countries the coefficient of the linear term of openness index is statistically significant and negative, the sign of the quadratic term is positive, but insignificant. This implies that in the annex-I countries, openness of the economy leads to decrease in EE. For the non-annex-I countries the sign of the linear and quadratic terms of openness index are negative and positive respectively, and statistically significant. This implies that there is deterioration in EE up to a certain level of openness and then the EE starts to improve once a critical threshold level of openness is reached. This finding concurs with the findings of Etkins *et. al.*, (1994), and Taskin and Zaim (2001).

Environmental Productivity of Countries

Table 4 sums up the main results concerning productivity change. Instead of presenting the disaggregated results for each year, we present a summary description of the cumulative performance of each group at the interval of five years. Recall that index values greater (less) than one denote improvements (deterioration) in the relevant performance. Here we have calculated the Malmquist index and its components for both cases: weak and strong disposability of CO_2. Our method of computing productivity change utilises a fixed base year (1971), and compares all subsequent years to that base.

The cumulative MS value of 0.843 indicates that the annual productivity decline was 0.8 per cent for the period 1971-92 when CO_2 is strongly disposable. On average, this decline was due to technological regression rather than decline in efficiency. The decline in TFP was 1.4 per cent for non-annex-I countries whereas in annex-I countries it declined only by 0.2 per cent per year. Moreover, the results shows that at country level there was technological stagnation in annex-I countries, but there was technological regression in developing countries (non-annex-I countries). Nigeria experienced the highest decline in TFP among the developing countries. The rate of TFP decline was 1.9 per cent per year, most of which is due to technological regression. Hong Kong experienced the least decline in MS, i.e. 1 per cent per year, and it was the country in the concerned group that experienced highest rate of ‘catch-up’ effect (EC), i.e. 0.2 per cent per year. In non-annex-I countries, Israel and Venezuela also experienced some of the positive catch-up effect. From these figures of stagnation in cumulative TFP changes in developed countries and decline in developing countries it may be argued that effectively all GDP growth in the post-1970 period was due to high rates of input accumulation.

The cumulative change in the MW was -11.4 per cent. This average TFP change was the product of a decline in innovations by 11.5 per cent and growth in EC by 0.01 per cent. All non-annex-I counties have technological regression when CO_2 was considered an undesirable output. But annex-I countries experienced a positive change in innovations, except Greece and Spain. Kopp (1998) also finds that, between 1970 and 1990, developed countries experienced technical progress in a way that economises on CO_2 emissions but that developing countries did not. In the non-annex-I countries, India experienced the highest and Paraguay experienced the least decline in TFP index, i.e. 28.4 and 17.4 per cent respectively. In the annex-I countries, Switzerland experienced the highest growth in TFP of the amount of 6.3 per cent; half of which comes from 'catch-up' effect. Belgium, Denmark, France, Japan, Luxembourg, Sweden and United States were the countries that had more than 2 per cent positive change in the Malmquist index between 1971 and 1992. But it was technological changes that governed the change in overall productivity indices in all countries.

Recall that the EP is measured as a ratio of TFP measured under weak and strong disposability of CO_2 emissions. Table 4 (last column) reports the cumulative value of EP index at certain points for both of the groups. Figure 4 reveals that the EP is increasing over time in both of the groups, but the rate of growth is higher in annex-I countries in comparison to the non-annex-I countries. In annex-I countries the cumulative increase in EP was 6.2 per cent whereas the non-annex-I countries experienced only 4.2 per cent increase during 1971 to 1992. In non-annex-I countries the countries having more than 10 per cent increase in EP were Nigeria (16.9 per cent), Zambia (15.8 per cent), Kenya (15.7 per cent), Paraguay (12.3 per cent), Morocco (10.8 per cent) and India (10.2 per cent), but in annex-I countries only Switzerland (11.8 per cent) experienced an increase higher than 10 per cent. Some countries experienced decline in the EP: Hong Kong (5 per cent), Venezuela (4.3 per cent), Mexico (2.6 per cent), Ecuador (1.9 per cent), Peru (1.6 per cent), Colombia (1.5 per cent) and Syrian Arab Republic (0.6 per cent). All these countries were non-annex-I countries and in annex-I no country experienced decline in EP. Thus there was higher variability in EP index among developing countries in comparison to the developed one. Moreover, the gap over time in EP was increasing between these two groups (Figure 6).

Determinants of Environmental Productivity

We hypothesise that the level of EP is determined by the level of GDP per capita, capital per labour, share of industrial output in GDP, energy intensity, population density and openness index. One important attribute that influences the environmental concerns and EP in a country is the per capita GDP. Therefore, we hypothesise an EKC type relationship between per capita income and EP. The relationship with the openness variable will determine the impact of international trade on the EP growth.

The equation below specifies a possible form relation between the EP and its determinants:

$$
\begin{aligned}
EP_{it} &= \beta_{1i} + \beta_2 GDPPC_{it} + \beta_3 (GDPPC)^2_{it} + \beta_4 INDSHARE_{it} \\
&+ \beta_5 CAPLAB_{it} + \beta_6 ENGDP_{it} + \beta_7 POPDENS_{it} + \beta_8 OPEN_{it} \\
&+ \beta_9 (OPEN)^2_{it} + \varepsilon_{it}
\end{aligned}
$$

where: i is country index; t is time index; ε is the disturbance term such that $\varepsilon \sim N(0, \sigma_\varepsilon)$; GDPPC is GDP per capita; INDSHARE is share of industrial output in GDP; CAPLAB is capital per labour; ENGDP is use of commercial energy per unit of GDP; POPDENS is population density; and OPEN, openness index defined as the ratio of total exports and imports to GDP.

Table 6 provides the parameters estimates of the regressions for the EP index under alternative specifications. A LM test performed on the alternative specifications of the fixed effect models accepts the null hypothesis of a common intercept against the model with country specific intercept terms for both groups. Further more the choice between fixed effect model and the random effect model can be made using the Hausman test. For both groups, we accept the null hypothesis, which suggests that the fixed effect model with common intercept term is the appropriate specification. The signs and significances of all coefficients are however robust across alternative models.

For the annex-I countries, we find that coefficients for GDP per capita and its quadratic term, capital-labour ratio, energy intensity, population density and openness and its quadratic terms are statistically significant. All other coefficients are insignificant. For the non-annex-I countries, we find that only three variables, i.e., energy intensity, capital per labour and population density are statistically significant variables. In the annex-I countries, there is presence of positive relationship between capital per labour and EP implying that capital intensity leads to increase in EP. But in the non-annex-I countries an increase in the capital intensity decreases EP. Furthermore, the population density is negatively affecting EP for both groups.

We find that energy intensity contributes positively to EP as its coefficient is positive for both groups of countries. Here it should be noted that EP can, like conventional measure of productivity, be decomposed into environmental efficiency change and environmental technical change. In the analysis of EE, we observed that energy intensity leads to decline in EE. Therefore, the positive relationship between energy intensity and EP implies that it may be the energy intensity that is encouraging environment friendly technological changes.

Of particular interest are the signs and significance of the coefficients of GDP per capita and its quadratic term, and openness index and its quadratic term. In the annex-I countries it is found that there is an improvement in EP up to per capita GDP level of approximately US$ 43,000, (Figure 7) but a phase of deterioration after that. But in the non-annex-I countries, it is found that at the initial phases of growth (up to per capita GDP level of approximately US$ 5,500, Figure 8) there is an improvement in EP which is followed by a phase of deterioration. Here it should be noted that for the non-annex-I countries the coefficients of GDP per capita and its quadratic terms are statistically insignificant even at the 10 per cent critical level. This implies that there exists an EKC type relationship for EP in annex-I countries (Figure 7).

Moreover, the openness variable also exhibits a U-curve type relationship with EP. For the annex-I countries the sign of the linear and quadratic terms of openness index are as expected and statistically significant. This implies that there is deterioration in environmental performance up to a certain level of openness and then the environmental performance starts to improve once a critical threshold level is reached. The negative effect of international trade may be due to energy related environmental damage such as carbon emissions that stem from increased transportation that is more pronounced below a threshold level of openness. However, as the degree of openness increases, this negative effect seems to be offset by the positive effects of harmonisation of international environmental standards. For the non-annex-I countries, the signs of the coefficients of openness are as expected, but these are statistically insignificant even at the 10 per cent critical level. The main explanatory variables explaining EP in non annex I countries are population density and energy intensity.

V. Conclusion

This paper develops EE and EP indexes using production frontier analysis, and compares them across countries, and over time. The particular emphasis is on the transformation of production processes that allow free disposability of carbon emissions to costly disposal of these emissions to construct these indexes. As opposed to methods which measure the environmental quality with the levels of emissions of pollutants, the indexes that are derived in this study are based upon a production approach that differentiates between the disposability characteristics of the environmentally desirable and undesirable outputs.

EE and EP indexes are calculated using the parametric input distance function for two groups annex–I and non-annex-I each having 21 countries for the period of 1971 to 1992.On average, the world has witnessed environmentally binding production technology during these two decades. The opportunity cost of the transformation of the production process from free to costly disposal of CO_2 emission was about 2 per cent of GDP. The relative output loss due to imposition of costly disposal of CO_2 emissions for non-annex-I group was higher than the average. The EE index was almost steady for the annex-I group, while its value is declining for non-annex-I group over time.

TFP measures show that the progress witnessed by the world during the 1970s and 1980s was due to factor accumulation rather than improvement in the productivity of factors of production. EP measured as the ratio of TFP under weak to strong disposability of CO_2 emissions shows that it increased over time in both the groups. However, the rate of growth was higher in annex-I countries in comparison to their counterpart non-annex-I countries.

A closer inspection of the EE index reveals that there was an improvement in EE in the initial phases of growth followed by a phase of deterioration and then a further improvement once a critical level of per capita GDP was reached in the annex-I countries. This finding is similar in spirit to the results obtained in an EKC analysis. But the situation is just opposite in the group containing non-annex-I countries. In the annex-I countries, the opportunity cost of the transformation of a production process from free to costly disposal of CO_2 emission is becoming smaller after a certain threshold income level. But the non-annex-I countries are far behind in development in comparison to the annex-I countries, and the opportunity costs of transformation in the production process are increasing. This study also find an EKC type relationship for the EP index in annex-I countries. A closer inspection of these indexes reveals that after accounting for the effect of changes in per capita income level on EE and EP, there remains some variation in these indexes that can be explained by energy intensity, degree of industrialisation, capital per labour, trade related variables etc. We also find in general that openness initially has a negative impact on EE and EP but that the effect increases as openness increases further. This implies that initially trade liberalisation negatively affects the environmental performance of countries as they strive to compete in the world market but as they become more integrated with the world markets, their environmental performance improves.

Table 1: Descriptive Statistics of the Variables Used in the Study (1971-1992)

Variable	Mean	Std. dev.	Minimum	Maximum
Annex-1 Countries				
GDP growth rate	2.662	0.750	1.398	3.900
CO_2 growth rate	0.414	1.700	-2.934	4.148
Labour growth rate	1.184	0.602	0.464	2.409
Capital growth rate	4.142	1.164	2.476	6.941
Energy consumption growth rate	1.293	2.164	-6.405	3.855
Industry share (per cent GDP)	35.073	4.107	25.661	46.489
Capital per labour (US$)	29227.530	11088.051	9721.000	76733.000
GDP per capita (US$)	20755.585	7628.875	8039.286	45951.950
Energy/GDP (metric tones/million US$)	0.285	0.141	0.006	0.761
Population density	111.589	119.804	1.684	447.993
Openness (export+import as per cent GDP)	65.601	40.745	11.239	233.537
Non-Annex-I Countries				
GDP growth rate	3.708	1.870	0.820	7.880
CO_2 growth rate	3.911	2.920	-2.755	9.143
Labour growth rate	3.030	0.483	2.052	4.033
Capital growth rate	4.312	2.252	-1.218	8.245
Energy consumption growth rate	3.884	1.811	0.682	8.698
Industry share (per cent GDP)	31.496	8.299	17.343	59.837
Capital per labour (US$)	7352.907	5988.130	349.000	22307.000
GDP per capita (US$)	2775.676	3813.108	205.645	20963.160
Energy/GDP (metric tones/million US$)	0.972	0.882	0.127	4.57
Population density	296.451	1072.136	3.979	5860.101
Openness (export+import as per cent GDP)	56.278	38.467	8.365	274.955

Table 2: Parameter Estimates of Input Distance Function

	Annex-I Countries		Non-Annex-I Countries	
	$D_i(\mathbf{x},\mathbf{y})*$	$D_i(\mathbf{x},\mathbf{y})**$	$D_i(\mathbf{x},\mathbf{y})*$	$D_i(\mathbf{x},\mathbf{y})**$
GDP	-1.073	-0.823	-1.141	-0.098
CO_2	.	-0.154	.	-0.704
Labour	0.579	0.632	1.133	-0.187
Capital	0.285	0.301	-0.003	0.462
Energy	0.136	0.067	-0.13	0.725
Time	-0.002	0.012	0.006	-0.022
GDP^2	0.002	0.019	0.004	0.012
${CO_2}^2$	.	-0.005	.	-0.04
$Labour^2$	0.027	0.026	-0.018	-0.011
$Capital^2$	-0.051	-0.024	-0.009	-0.005
$Energy^2$	-9.22E-04	-8.62E-04	-0.023	-0.011
$Time^2$	2.13E-05	3.98E-05	2.12E-05	1.29E-05
GDP×CO_2	.	-0.013	.	0.027
Labour×Capital	0.004	-0.016	-0.079	0.004
Labour×Energy	0.013	0.005	0.092	0.033
Capital×Energy	0.009	0.009	0.037	-0.009
GDP×Labour	-0.063	-0.047	0.019	0.018
GDP×Capital	0.084	0.035	0.057	-0.019
GDP×Energy	-0.021	-0.014	-0.076	-0.057
GDP×Time	-0.002	-0.002	2.29E-05	5.06E-04
CO_2×Labour	.	0.008	.	-0.033
CO_2×Capital	.	0.019	.	0.029
CO_2×Energy	.	-9.57E-04	.	0.062
CO_2×Time	.	-2.23E-04	.	-9.52E-04
Labour×Time	-1.90E-04	0.002	0.002	4.46E-04
Capital×Time	0.002	4.87E-04	-0.001	6.98E-04
Energy×Time	6.27E-05	-2.50E-04	-6.20E-05	-6.47E-04
Intercept	5.084	2.23	5.115	-3.189

Note: $D_i(\mathbf{x},\mathbf{y})$ *: CO_2 is strongly disposable; $D_i(\mathbf{x},\mathbf{y})$ **: CO_2 is weakly disposable.

Table 3: Descriptive Statistics of Efficiency Measures (Geometric Mean)

Year	$D_i(\mathbf{x},\mathbf{y})$ *				$D_i(\mathbf{x},\mathbf{y})$ **				Environmental Efficiency			
	Mean	**S.D.**	**Max**	**Min**	**Mean**	**S.D.**	**Max**	**Min**	**Mean**	**S.D.**	**Max**	**Min**
Annex-I Countries												
1971	1.014	0.012	1.050	1.000	1.004	0.007	1.033	1.000	0.996	0.006	1.000	0.977
1975	1.010	0.011	1.048	1.001	1.003	0.004	1.019	1.000	0.997	0.005	1.000	0.978
1980	1.007	0.010	1.046	1.000	1.002	0.004	1.017	1.000	0.997	0.005	1.000	0.978
1985	1.008	0.011	1.048	1.000	1.003	0.003	1.010	1.000	0.998	0.005	1.000	0.979
1990	1.010	0.012	1.052	1.000	1.005	0.004	1.014	1.000	0.997	0.005	1.000	0.978
1992	1.012	0.013	1.054	1.002	1.006	0.005	1.020	1.000	0.997	0.006	1.000	0.976
Non-Annex-I Countries												
1971	1.040	0.041	1.160	1.001	1.011	0.012	1.039	1.000	0.988	0.014	1.000	0.943
1975	1.044	0.037	1.146	1.002	1.011	0.010	1.038	1.000	0.985	0.013	1.000	0.946
1980	1.044	0.040	1.160	1.000	1.011	0.011	1.050	1.000	0.986	0.012	1.000	0.959
1985	1.046	0.040	1.143	1.003	1.011	0.012	1.048	1.001	0.985	0.016	1.000	0.954
1990	1.054	0.049	1.204	1.001	1.009	0.008	1.037	1.000	0.980	0.022	1.000	0.916
1992	1.057	0.051	1.209	1.002	1.007	0.008	1.029	1.000	0.977	0.023	1.000	0.909

Note: $D_i(\mathbf{x},\mathbf{y})$ *: CO_2 is strongly disposable, $D_i(\mathbf{x},\mathbf{y})$ **: CO_2 is weakly disposable.

Table 4: Cumulative Values of Malmquist Index, its Components and Environmental Productivity (1971=1)

	Strong Disposability of CO_2			Weak Disposability of CO_2			Environmental Productivity
Year	**EC**	**TC**	**MS**	**EC**	**TC**	**MW**	
			Annex-I Countries				
1975	1.003	0.993	0.996	1.001	1.004	1.005	1.009
1980	1.006	0.982	0.988	1.001	1.008	1.010	1.021
1985	1.006	0.971	0.977	1.001	1.012	1.012	1.037
1990	1.004	0.958	0.962	0.999	1.015	1.014	1.054
1992	1.001	0.953	0.954	0.998	1.016	1.014	1.062
			Non-Annex-I Countries				
1975	0.997	0.949	0.946	1.000	0.954	0.955	1.009
1980	0.997	0.889	0.886	1.001	0.898	0.899	1.014
1985	0.994	0.832	0.827	1.000	0.844	0.844	1.021
1990	0.987	0.777	0.767	1.003	0.792	0.794	1.034
1992	0.984	0.756	0.744	1.004	0.772	0.775	1.042

Note: EC, Efficiency Change; TC, Technical Change; MS, Malmquist Index under strong disposability; MW, Malmquist Index under weak disposability.

Table 5: Determinants of Environmental Efficiency (EE)

Variable	Annex-I Countries			Non-Annex-I Countries		
	Constant intercept	Fixed Effect	Random Effect	Constant intercept	Fixed Effect	Random Effect
GDPPC	5.27E-05	5.70E-05	5.52E-05	-2.16E-04	-2.05E-04	-2.16E-04
	(7.287)*	(7.973)*	(7.754)*	(-5.766)*	(-5.390)*	(-5.701)*
$(GDPPC)^2$	-1.90E-09	-2.11E-09	-2.03E-09	2.75E-08	2.51E-08	2.74E-08
	(-5.763)*	(-6.452)*	(-6.230)*	(4.982)*	(4.438) *	(4.922) *
$(GDPPC)^3$	2.05E-14	2.34E-14	2.23E-14	-9.07E-13	-7.82E-13	-9.05E-13
	(4.368) *	(5.013) *	(4.809) *	(-4.045) *	(-3.363) *	(-3.992) *
INDUSTRY	-7.79E-03	-1.74E-02	-1.40E-02	1.60E-02	1.69E-02	1.60E-02
	(-1.009)	(-2.171) **	(-1.794) ***	(1.614)	(1.634)	(1.597)
$(INDUSTRY)^2$	1.19E-04	2.66E-04	2.13E-04	-2.53E-04	-2.66E-04	-2.53E-04
	(1.083)	(2.336) **	(1.907) ***	(-1.722) ***	(-1.738) ***	(-1.704) ***
CAPLAB	7.68E-07	2.88E-07	5.35E-07	2.00E-05	2.06E-05	2.00E-05
	(2.267) **	(0.793)	(1.541)	(6.267) *	(6.337) *	(6.203) *
ENGDP	-3.91E-02	-3.67E-02	-3.76E-02	-2.22E-01	-2.16E-01	-2.22E-01
	(-1.633)***	(-1.562)	(-1.601)	(-11.230) *	(-10.743) *	(-11.107) *
DENSITY	6.56E-05	5.29E-05	5.93E-05	-1.91E-04	-1.79E-04	-1.91E-04
	(2.223) **	(1.813) ***	(2.042) **	(-2.906) *	(-2.627) *	(-2.872) *
OPEN	-4.97E-04	-5.82E-04	-5.49E-04	-6.60E-03	-5.32E-03	-6.59E-03
	(-1.476)	(-1.758) ***	(-1.659) ***	(-3.708) *	(-2.817) *	(-3.656) *
$(OPEN)^2$	1.05E-06	1.59E-06	1.38E-06	3.57E-05	2.82E-05	3.56E-05
	(0.441)	(0.677)	(0.586)	(2.333) **	(1.761) ***	(2.300) **
Constant	-0.965		0.975	0.998		0.998
	(72.482) *		(72.316) *	(55.530) *		(54.904) *
R^2	.429	.481	0.429	0.409	0.428	0.409
LM Test (p-value)		1.50			2.17	
		(0.22)			(0.141)	
Hausman Test (p-value)			15.99			12.25
			(0.099) ***			(0.268)
N	416	416	416	408	408	408

Note: Values in parentheses represent 't-statistics'. *, **, and *** show the level of significance at 1 per cent, 5 per cent and 10 per cent respectively.

Table 6: Determinants of Environmental Productivity (EP)

Variable	Annex-I Countries			Non-Annex-I Countries		
	Constant intercept	Fixed Effect	Random Effect	Constant intercept	Fixed Effect	Random Effect
GDPPC	1.83E-06	1.95E-06	1.85E-06	5.60E-06	6.64E-06	6.18E-06
	(3.40)*	(3.51)*	(3.41)*	(0.916)	(1.09)	(1.02)
$(GDPPC)^2$	-2.15E-11	-2.49E-11	-2.21E-11	-4.92E-10	-5.70E-10	-5.34E-10
	(-1.69)***	(-1.89)***	(-1.72)***	(-0.871)	(-1.01)	(-0.954)
INDUSTRY	1.03E-04	1.87E-04	1.16E-04	2.94E-04	2.47E-04	2.67E-04
	(0.617)	(1.01)	(0.678)	(0.744)	(0.629)	(0.684)
CAPLAB	7.99E-07	7.42E-07	7.89E-07	-4.69E-06	-4.95E-06	-4.84E-06
	(8.66)*	(7.32)*	(8.37)*	(-6.75)*	(-7.12)*	(-6.99)*
ENGDP	1.59E-02	1.56E-02	1.58E-02	1.73E-02	1.69E-02	1.71E-02
	(2.51)**	(2.46)**	(2.49)**	(4.48)*	(4.44)*	(4.84)*
DENSITY	-1.30E-05	-1.40E-05	-1.32E-05	-3.31E-05	-3.19E-05	-3.23E-05
	(-1.67)***	(-1.76)***	(-1.68)***	(-3.00)*	(-2.83)*	(-2.92)*
OPEN	-1.93E-04	-2.07E-04	-1.97E-04	-2.98E-04	-3.61E-04	-3.32E-04
	(-2.06)**	(-2.19)**	(-2.09)	(-0.854)	(-1.02)	(-0.950)
$(OPEN)^2$	1.12E-06	1.19E-06	1.14E-06	4.98E-06	4.99E-06	4.97E-06
	(1.69)***	(1.77)***	(1.71)***	(1.52)	(1.51)	(1.52)
Constant	0.998		0.998	1.002		1.003
	(1172.18)*		(1154.48)*	(763.72)*		(742.46)*
R^2	0.479	0.503	0.479	0.32	0.372	0.32
LM Test (p-value)		0.37			1.80	
		(0.54)			(0.18)	
Hausman Test (p-value)			5.05			9.37
			(0.75)			(0.31)
N	397	397	397	388	388	388

Note: **Values in parentheses represent 't-statistics'. *, **, and *** show the level of significance at 1 per cent, 5 per cent and 10 per cent respectively.**

Figure 1: Environmental Efficiency Index

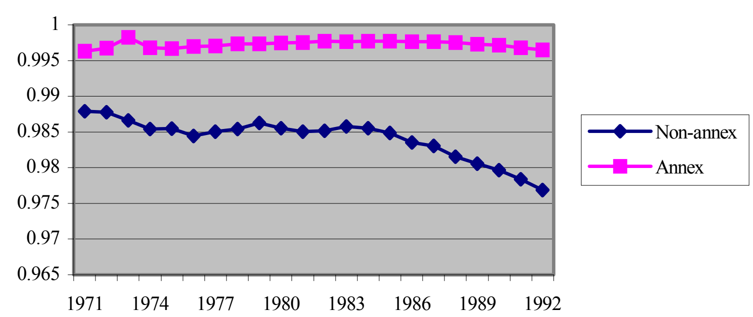


Figure 2: EKC in EE for Annex-I Countries

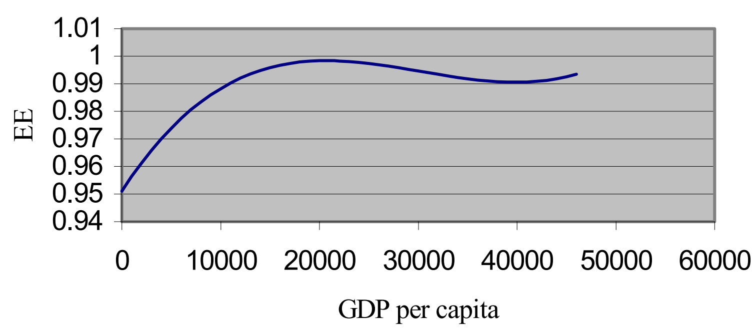


Figure 3: EKC in EE for Non-Annex-I Countries

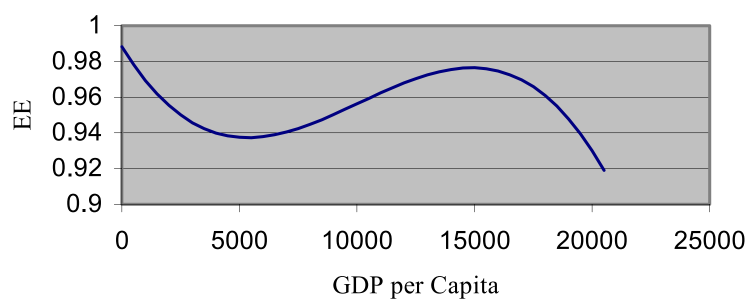


Figure 4: Conventional Malmquist Index (1971=1)

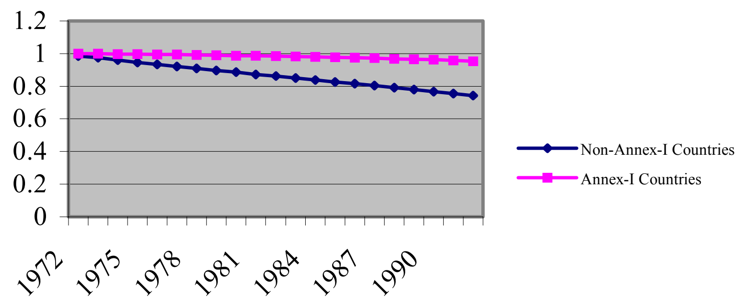


Figure 5: Environmentally Sensitive Malmquist Index (1971=1)

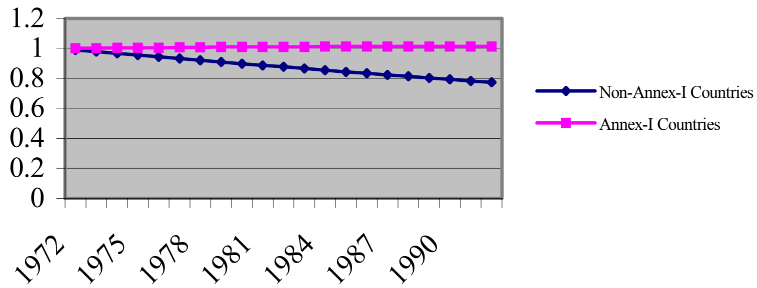


Figure 6: Environmental Productivity Index (1971=1)

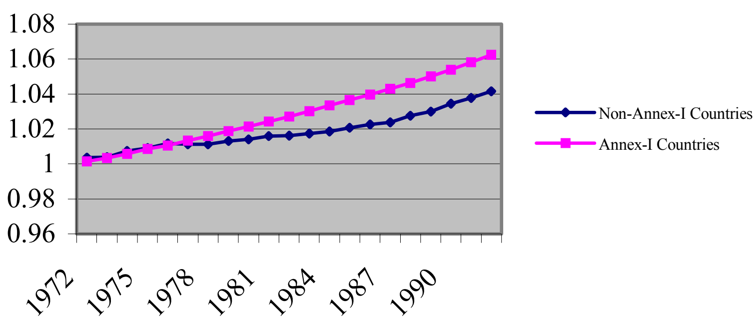


Figure 7: EKC in EP for Annex-I Countries

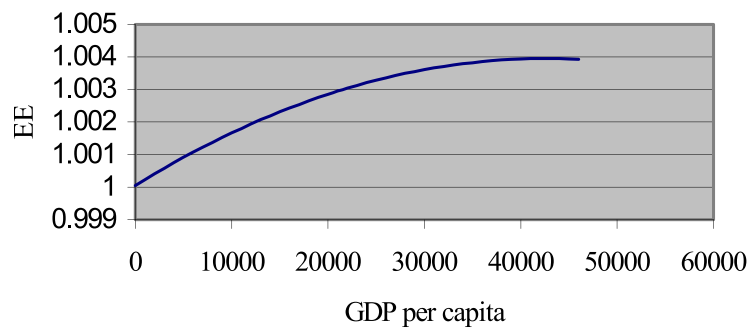
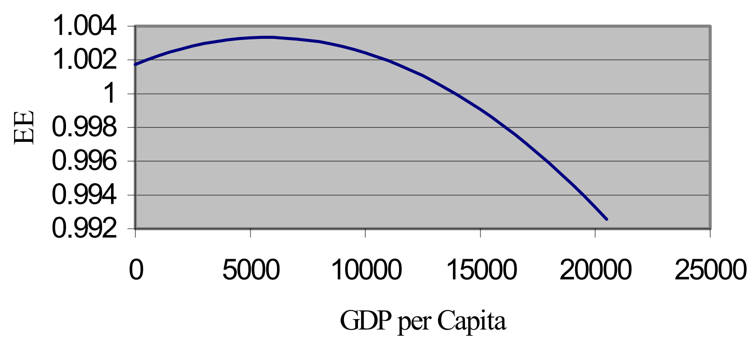


Figure 8: EKC in EP for Non-Annex-I Countries



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Endnotes

1 The annex-1 parties to the United Nations Framework Convention on Climate Change are those developed countries, or regional organisations (the EU), that are listed in the annex-I of the Climate Convention.

2 Cropper and Oates (1992); Pittman (1981); Haynes *et. al.,* (1993, 1994), Boggs (1997); Kopp (1998); Reinhard *et. al.,* (1999); Murty and Kumar (2004); etc.

3 This problem is discussed in the unpublished Appendix B of Fare, Grosskopf and Pasurka (2001) who calculated the Malmquist productivity index using directional output distance function for the manufacturing sectors of the 48 contiguous states of United States for 1974–1986.

4 Shafik and Bandyopadhyay (1992); Grossman and Krueger (1993); Cropper and Griffith (1994); Selden and Song (1994); Holtz-Easkin and Selden (1995); Dasgupta *et. al*., (2002); etc.

5 Fare *et. al*., (1986, 1989b), Fare *et. al.*, (1989a); Zaim and Taskin (2000); Takin and Zaim (2001); etc.

6 For the properties of input distance function, *see* Fare and Primont (1995).

7 http://earthtrends.wri.org/searchable_db/index.cfm?theme=3

8 Capital stock does not include residential construction but does include gross domestic investment in producers' durable, as well as non-residential construction. These are the cumulated and depreciated sums of past investment.

9 We have grouped all the countries in two categories annex-I and non-annex-I countries. We have 21 annex-I countries (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom, United States) and 21 non-annex-I countries (Bolivia, Chile, Colombia, Ecuador, Guatemala, Honduras, Hong Kong, India, Israel, Kenya, Mexico, Morocco, Nigeria, Paraguay, Peru, Philippines, Syrian Arab Republic, Thailand, Venezuela, Zambia and Zimbabwe).

10 Disaggregated results can be had from the authors on request.

11 For the effect of the population density variable on EE, there are alternative prior expectations in the literature. For example, Selden and Song (1994) hypothesised that 'sparsely populated countries are likely to be less concerned about reducing per capita emissions, at every of income, than more densely populated countries.' On the other hand Cropper and Griffiths (1994) found that high population density is a major cause of increased deforestation. Therefore, we expect a positive sign for POPDENS variable in annex-I countries and a negative sign for non-annex-I countries.