## Abstract

In a recent paper, Tyteca (1996) reviews the literature on environmental performance indicators. In that paper he calls for an index that simultaneously accounts for resources used, good outputs produced and pollutants or undesirable outputs emitted. Here we provide a formal index number of environmental performance which can be computed using DEA techniques. The implicit benchmark is that of finding the highest ratio of good to bad outputs. Our environmental performance index is constructed from distance functions which implies that it satisfies a number of desirable properties. Since the component distance functions require only information on input and output quantities, the fact that bad outputs typically are not marketed and therefore have no readily observable 'price' poses no osbtacle. We apply our method to a sample of OECD countries for 1990.

JEL Codes:
O47 Measurement of Aggregate Productivity
Q25 Environmental Managment, water;air

Keywords: index numbers, environmental quality

# Environmental Performance: An Index Number Approach

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# 1 Introduction

In a recent paper, Tyteca (1996) reviews the literature on environmental performance indicators. In that paper he calls for an index that simultaneously accounts for resources used, good outputs produced and pollutants or undesirable outputs emitted. He ultimately recommends using DEA approaches to evaluate environmental performance. Here we provide a formal index number of environmental performance which can be computed using DEA techniques. Our index measures the degree to which a firm (or plant or industry or country) has succeeded in producing good output while simultaneously accounting for reductions in bad outputs. In fact we propose a measure which consists of the ratio of a quantity index of good output to a quantity index of bad output. The implicit benchmark is that of finding the highest ratio of good to bad outputs, i.e., this can be thought of as a type of environmental productivity index.

Our environmental performance index is constructed from distance functions which implies that it satisfies a number of desirable properties. Since the component distance functions require only information on input and output quantities, the fact that bad outputs typically are not marketed and therefore have no readily observable 'price' poses no osbtacle. The distance functions are also straightforward to compute as we demonstrate for a sample of OECD countries for 1990. This example is meant to be illustrative of how our index may be estimated, and is not intended for policy prescriptions.

The paper is organized as follows. The next section introduces our methodology. In Section 3 we describe our data and results.

# 2 Methodology

In this section we develop our environmental performance index. A distinguishing feature of this index is that it is constructed as ratios of distance functions. These are perfect aggregator functions which provide a natural and elegant basis for constructing quantity indexes. Here we take advantage of these properties to construct a quantity index of good outputs and a quantity index of bad outputs. Their ratio is our environmental performance index.

We begin with some notation. We let the vector of inputs be represented by $x = (x_1, \ldots, x_N) \in \Re^N_+$, the vector of desirable outputs by $y = (y_1, \ldots, y_M) \in \Re^M_+$ and the undesirable outputs by $b = (b_1, \ldots, b_J) \in \Re^J_+$. The technology consists of all feasible vectors $(x, y, b)$ i.e.,

$$T = \{(x, y, b) : x \quad \text{can produce} \quad (y, b)\}.$$

To accurately model a technology that produces both good and bad or undesirable outputs we introduce the following two properties:

- If $(x, y, b) \in T$ and $0 \leq \theta \leq 1$ then $(x, \theta y, \theta b) \in T$.
- If $(x, y, b) \in T$ and $b = 0$ then $y = 0$.

The first property is weak disposability of outputs and it tells us that it is feasible to reduce good and bad outputs proportionally.[1]

The second property states that desirable and undesirable outputs are nulljoint, which means that it is technically (or economically) impossible to produce the good outputs without simultaneously producing some bad outputs. In fact the only feasible way to totally eliminate the bad outputs is by shutting down production of the desirable outputs.

In addition to weak disposability and nulljointness, we impose standard regularity conditions on $T$, eg. $T$ is a closed set and inputs and good outputs are freely disposable. For details see Färe and Primont (1995).

Now that we have specified a technology set which accounts for the distinctive characteristics of production with negative externalities, we turn to providing a function representation of that technology which may be used to both model and estimate the quantity indexes we seek. Here we take the 'direct' approach and employ generalizations of production functions which allow us to include the distinctive properties of nulljointness and weak disposability. These are called distance functions and play an interesting role

[1] However, it may not be feasible to reduce only the bad outputs, keeping inputs and good outputs fixed.

in the recent history of index number theory.[2]

We begin by defining a Shephard (1970) output distance function for the subvector of good outputs, i.e.,

$$D_{\mathsf{y}}(x,y,b) \;=\; \inf\{\theta : (x, y/\theta, b) \in T\}, \tag{1}$$

where the infimum is $\theta^* \;=\; D_{\mathsf{y}}(x,y,b)$. This function serves as representation of technology, aggregator function and performance measure. It is homogeneous of degree $+1$ in good outputs and it inherits its properties from the technology $T$.

This distance function is the basis of our first quantity index–namely our index of good outputs. Let $x^{\mathsf{o}}$ and $b^{\mathsf{o}}$ be given vectors of inputs and bad outputs and let $y^{\mathsf{k}}$ and $y^{\mathsf{l}}$ be two observations of the vector of good outputs which our index will be comparing. As is the standard convention in the index number literature, $k, l$ and $o$ can refer to observations of a given firm–for example in different time periods–or it may refer to different firms in a single period. Following the general idea proposed by Malmquist (in the consumer context), we define our quantity index of good outputs as

$$Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{k}}, y^{\mathsf{l}}) \;=\; D_{\mathsf{y}}(x^{\mathsf{o}}, y^{\mathsf{k}}, b^{\mathsf{o}})/D_{\mathsf{y}}(x^{\mathsf{o}}, y^{\mathsf{l}}, b^{\mathsf{o}}). \tag{2}$$

This index indicates whether the vector of good outputs $y^{\mathsf{k}}$ is larger or smaller than the vector of good outputs $y^{\mathsf{l}}$. One can verify that the index satisfies the following tests (or properties) due to Fisher (1922).

- Homogeneity: $Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, \lambda y^{\mathsf{k}}, y^{\mathsf{l}}) \;=\; \lambda Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{k}}, y^{\mathsf{l}})$.
- Time-Reversal: $Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{k}}, y^{\mathsf{l}}) \cdot Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{l}}, y^{\mathsf{k}}) = 1$
- Transitivity: $Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{k}}, y^{\mathsf{l}}) \cdot Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{l}}, y^{\mathsf{s}}) \;=\; Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{k}}, y^{\mathsf{s}})$.
- Dimensionality: $Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, \lambda y^{\mathsf{k}}, \lambda y^{\mathsf{l}}) = Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{k}}, y^{\mathsf{l}})$.

[2] Specifically in a pathbreaking paper, Malmquist (1953) showed that economic quantity indexes may be defined as ratios of distance functions.

We now turn to constructing a quantity index of the bad outputs. We begin by defining a distance function that reduces rather than increases these undesirable outputs. This means that we define a Shephard (1953) type input distance function for the subvector of bad outputs, i.e.,

$$D_{\mathsf{b}}(x, y, b) \;=\; \sup\{\lambda : (x, y, b/\lambda) \in T\}. \tag{3}$$

This function is homogeneous of degree +1 in bad outputs and it also inherits its properties from the technology $T$. Let $x^{\mathsf{o}}$ and $y^{\mathsf{o}}$ be given inputs and good outputs and now let $b^{\mathsf{k}}$ and $b^{\mathsf{l}}$ be the two vectors we wish to compare in our index. The bad quantity index is defined by the ratio

$$Q_{\mathsf{b}}(x^{\mathsf{o}}, y^{\mathsf{o}}, b^{\mathsf{k}}, b^{\mathsf{l}}) = D_{\mathsf{b}}(x^{\mathsf{o}}, y^{\mathsf{o}}, b^{\mathsf{k}})/D_{\mathsf{b}}(x^{\mathsf{o}}, y^{\mathsf{o}}, b^{\mathsf{l}}). \tag{4}$$

This index also satisfies the four Fisher tests listed above.

Following in the tradition of the Hicks-Moorsteen productivity index,[3] we define our environmental performance index as

$$E^{\mathsf{k,l}}(x^{\mathsf{o}}, y^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{k}}, y^{\mathsf{l}}, b^{\mathsf{k}}, b^{\mathsf{l}}) \;=\; \frac{Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{k}}, y^{\mathsf{l}})}{Q_{\mathsf{b}}(x^{\mathsf{o}}, y^{\mathsf{o}}, b^{\mathsf{k}}, b^{\mathsf{l}})}. \tag{5}$$

In order to provide some intuition, consider the very simple case in which we have one good output and one bad output. Due to the homogeneity of the distance functions, $D_{\mathsf{y}}(\cdot)$ and $D_{\mathsf{b}}(\cdot)$, our index takes the following form:

$$E^{\mathsf{k,l}}(\cdot) \;=\; \frac{y^{\mathsf{k}}/y^{\mathsf{l}}}{b^{\mathsf{k}}/b^{\mathsf{l}}} \;=\; \frac{y^{\mathsf{k}}/b^{\mathsf{k}}}{y^{\mathsf{l}}/b^{\mathsf{l}}}. \tag{6}$$

Thus our index evaluates environmental performance on the basis of the ratio of goods to bads for $k$ and $l$.

In the case in which there are more than one good and bad, the component distance functions may be computed in a number of ways. Perhaps the simplest is as the solution to a simple linear programming problem, familiar from the efficiency measurement literature. In our application, we have a cross-section of countries in one year. Thus we are computing a multilateral index. In our case we choose the first country, Austria, as our reference, thus

[3] See Diewert (1992) for a reference.

we are assuming that $l = o$, which then refers to the associated quantities for Austria in that year. We let $k = 1, \ldots, K$ index the countries in the sample. Here we take advantage of the fact that distance functions are reciprocals of Farrell technical efficiency measures and compute them as solutions to simple linear programming problems.[4] Thus for each, $k' = 1, \ldots, K$ we may compute

$$\begin{aligned}
(D_y(x^o, y^{k'}, b^o))^{-1} &= \max \theta \qquad (7)\\
s.t. \sum_{k=1}^{K} z_k y_m^k &\geq \theta y_m^{k'}, m = 1, \ldots, M\\
\sum_{k=1}^{K} z_k b_j^k &= b_j^o, j = 1, \ldots, J\\
\sum_{k=1}^{K} z_k x_n^k &\leq x_n^o, n = 1, \ldots, N\\
z_k &\geq 0, k = 1, \ldots, K,
\end{aligned}$$

which is the numerator for $Q_y(x^o, b^o, y^k, y^l)$. The denominator is computed by replacing $y^{k'}$ on the right-hand-side of the good output constraints with the observed output for Austria, i.e., $y^o$. This problem constructs the best practice frontier from the observed data, and computes the scaling factor on good outputs required for each observation to attain best practice. The strict equality on the bad output constraints serves to impose weak disposability and null jointness.

For the bad index we compute for each $k' = 1, \ldots, K$

$$\begin{aligned}
(D_b(x^o, y^o, b^{k'}))^{-1} &= \min \lambda \qquad (8)\\
s.t. \sum_{k=1}^{K} z_k y_m^k &\geq y_m^o, m = 1, \ldots, M\\
\sum_{k=1}^{K} z_k b_j^k &= \lambda b_j^{k'}, j = 1, \ldots, J
\end{aligned}$$

[4] This is also known as DEA, or data envelopment analysis.

$$\sum_{k=1}^{K} z_k x_n^k \leq x_n^o, n = 1, \ldots, N$$
$$z_k \geq 0, k = 1, \ldots, K,$$

which is the numerator for $Q_b(x^o, y^o, b^k, b^l)$. The denominator is computed by replacing $b^{k'}$ on the right-hand-side of the bad output constraints with the observed bad outputs for Austria, i.e., $b^o$. As above, this problem constructs the best practice frontier from the observed data, and computes the scaling factor on bad outputs required for each observation to attain best practice.

# 3 Data and Variables

The statistical information used in this paper comes from a cross-section data set of 19 OECD countries for the year 1990. The sources of the data are the International Energy Agency, and the Penn World Tables. We employ the following variables: GDP (Gross Domestic Production measured in billions of US $1990) as desirable output; CO2 (Carbon dioxide emissions from energy use in millions of tonnes), NOx (Nitrogen oxide emissions in thousands of tonnes) and SO2 (sulfur dioxide emissions in thousands of tonnes) as undesirable outputs; oil consumption (measured in Mtoe.), L (Labor expressed as number of workers in thousands) and CS (Capital Stock measured in trillions of US $1990) as inputs (see Table I).

The three pollutants we consider in this paper–carbon dioxide (CO2), sulfur dioxide (SO2) and nitrogen oxides (NOx)–are significant because they have detrimental environmental impacts. Carbon dioxide is the main contributor to global warming and nitrogen oxides can reduce plant growth and cause damage to plant crops, also contributing to acidification and the formation of ground-level ozone. In most countries, the production of electricity, combustion in industry, road transport and other non-industrial combustion are the main sources of the pollutants considered here.

## 3.1 Results

The outcomes obtained using the methodology presented above are shown in Table II. As mentioned above, Austria has been used as reference to calculate our multilateral Environmental Index ($E^{k,o}(\cdot)$ as well as the quantity index of good outputs ($Q_y(x^o, b^o, y^k, y^l)$) and the quantity index of bad outputs ($Q_b(x^o, y^o, b^k, b^l)$) for each of the OECD countries in our sample. We present results for the case in which we included all three undesirable outputs.[5]. For our most general case the average value of the overall indicator for the sample is 1.0113, whereas the good output quantity index averages 5.0321 and the bad quantity index averages 8.91 . The overall indicator for Germany is by far the highest, suggesting to us that it is an outlier. The next highest overall indicator belongs to the Netherlands and the worst belongs to Ireland. Interestingly, the U.S. ranks second lowest based on the overall indicator. We note that our overall index has a much smaller variation than either the good or bad index; the ratio effectively adjusts for differences in scale across countries.

Table I

DESCRIPTIVE STATISTICS
1990, 19 OECD countries

| Variable | Description | Units | Mean |
|---|---|---|---|
| GDP | Gross Domestic Product | Billion US$ | 514.46 |
| CO2 | Carbon dioxide | Million Tons | 462.89 |
| NOx | Nitrogen oxides | Thousand Tons | 1913.05 |
| EC | Oil Consumption | Mtoe. | 70.46 |
| L | Labour | Thousand Workers | 16927.95 |
| CS | Capital Stock | Trillion US$ | 540.20 |

[5] We also estimated our results using models with just two of the undesirable outputs at a time–the qualitative results in terms of our nonparametric tests are similar. These are included in the appendix

Table 2

Multilateral Indexes, CO2, NOx, SO2: 1990

| COUNTRY | $Q_y(x^o, b^o, y^k, y^l)$ | $Q_b(x^o, y^o, b^k, b^l)$ | $E$ |
|---|---|---|---|
| AUSTRIA | 1 | 1 | 1 |
| BELGIUM | 1.3471 | 1.578 | 0.8535 |
| CANADA | 4.6521 | 8.241 | 0.5645 |
| DENMARK | 0.7304 | 1.179 | 0.6195 |
| FINLAND | 0.716 | 1.17 | 0.612 |
| FRANCE | 8.0573 | 7.107 | 1.1337 |
| GREECE | 0.6998 | 1.348 | 0.5191 |
| IRELAND | 0.3318 | 1 | 0.3318 |
| ITALY | 7.3549 | 8.892 | 0.8272 |
| NETHERLANDS | 1.9898 | 1 | 1.9898 |
| NORWAY | 0.6457 | 1 | 0.6457 |
| PORTUGAL | 0.7537 | 1 | 0.7537 |
| SPAIN | 3.8134 | 1 | 3.8134 |
| SWEDEN | 1.2905 | 1 | 1.2905 |
| SWITZERLAND | 1.1315 | 1 | 1.1315 |
| U.K. | 7.7505 | 11.868 | 0.6531 |
| U.S.A. | 46.17 | 102.081 | 0.4523 |
| Mean | 5.0321 | 8.91 | 1.0113 |

It is well known that during the past two decades, the developed countries have made important efforts in reducing emissions of pollutants to air such as CO2, SO2 and NOx, although these have not been equally important for all economic sectors or across all OECD countries. It would be interesting to know the factors associated with improvements in environmental performance in the different countries. Although that is best addressed in a panel data context, here we attempt to isolate some of the sources of variation in our indicator for our cross section results.

We run a battery of nonparametric tests to determine if a relationship exists between the overall environmental indicator and some basic country characteristics. The sample is broken into two groups; group A includes those countries with environmental performance below the median indicator for the sample (Ireland, Greece, U.S., Canada, Turkey, Portugal, U.K., Spain, the Netherlands and Denmark) while group B comprises all those countries with environmental performance equal to or better than the median (Finland, Belgium, Italy, Norway, France, Austria, Sweden, Switzerland)[6]. We use the battery of tests available in the PROC NPAR1WAY procedure in SAS to ascertain whether there is a statistically significant difference between the two groups with respect to GDP/Population and Oil Consumption/GDP.[7]

The main results are as follows. First, we find no significant difference in GDP/Population across the two groups of countries: countries of group A (those with a below median environmental index) are not systematically different in terms of per capita GDP from those in our group B (those with above median performance). According to the general presumption underlying the notion of a Kuznets curve, increases in GDP per capita should eventually be associated with increased demand for higher environmental quality. Previous studies have found mixed evidence concerning the existence of this relationship depending on the particular pollutant–most studies generally consider only one pollutant at a time. On this basis, CO2 has been found to be positively related to GDP per capita, whereas many of the other pollutants considered individually have been found to have an eventually negative relationship to per capita income. Our index, which simultaneously accounts for CO2, SOx and NOx, suggests that there may be no clearcut relationship overall.[8] In contrast to earlier work, our index also simultaneously accounts for the production of goods and for the use of inputs through the distance functions used to estimate the indexes. Finally, the small sample of countries used here for a single year may not be capable of revealing the time series relationships we seek to reveal.

Returning to the nonparametric test results, Oil consumption/GDP varies significantly across our two groups of countries (those above and those below the median level of environmental performance) for a confidence level

[6] We omit Germany from this analysis.

[7] Tests included in this procedure are: median, Mann-Whitney, Van der Waerden, Savage, Kolmogorov-Smirnov, and Cramer-von Mises.

[8] We also found no significant relationship for the cases in which we included only CO2 and NOx, and the case in which we included only CO2 and SOx.

of 95 percent.[9] The countries that are below the median in environmental performance are relatively more intensive in the use of oil in relation to output. The list of countries which includes those relatively low environmental performance in our sample clearly include countries that are dependent on oil–the U.S. and Canada are in this category. Although we are unwilling to base any strong policy recommendations on these results, they would suggest the obvious idea that oil conservation on the part of oil-dependent rich countries would be environmentally beneficial.

Although our purpose here was to provide an illustrative example of how our index may be estimated, given data availability, this work could be extended to look at our environmental performance indexes over time, in which case one may exploit the panel nature of such a data set to compute these indexes across time, which means that one would no longer have to choose a reference country to form the benchmark. This would provide more direct evidence concerning the Kuznets curve relationship as the index would track country performance over time, allowing for more direct inferences concerning economic growth and environmental performance.

[9] The results were qualitatively similar for the two pollutant cases included in the appendix.

# 4 Appendix

Table A1

Multilateral Indexes, CO2, NOx: 1990

| COUNTRY | $Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{k}}, y^{\mathsf{l}})$ | $Q_{\mathsf{b}}(x^{\mathsf{o}}, y^{\mathsf{o}}, b^{\mathsf{k}}, b^{\mathsf{l}})$ | $E$ |
|---|---:|---:|---:|
| AUSTRIA | 1 | 1 | 1 |
| BELGIUM | 1.3471 | 1.5197 | 0.8864 |
| CANADA | 4.6521 | 8.3826 | 0.555 |
| DENMARK | 0.7304 | 1.0414 | 0.7013 |
| FINLAND | 0.716 | 1.0628 | 0.6737 |
| FRANCE | 8.0573 | 7.1882 | 1.1209 |
| GREECE | 0.6998 | 1.3917 | 0.5028 |
| IRELAND | 0.3318 | 0.8735 | 0.3799 |
| ITALY | 7.3549 | 7.985 | 0.9211 |
| NETHERLANDS | 1.9898 | 2.5879 | 0.7689 |
| NORWAY | 0.6457 | 0.8735 | 0.7392 |
| PORTUGAL | 0.7537 | 0.8735 | 0.8628 |
| SPAIN | 3.8134 | 4.2763 | 0.8918 |
| SWEDEN | 1.2905 | 0.8735 | 1.4774 |
| SWITZERLAND | 1.1315 | 0.8735 | 1.2953 |
| TURKEY | 2.1436 | 2.3143 | 0.9262 |
| U.K. | 7.7505 | 11.3854 | 0.6807 |
| U.S.A. | 46.17 | 90.4828 | 0.5103 |
| Mean | 5.0321 | 8.0548 | 0.8274 |

Table A2

Multilateral Indexes, CO2, SO2: 1990

| COUNTRY | $Q_{\mathsf{y}}(x^{\mathsf{o}}, b^{\mathsf{o}}, y^{\mathsf{k}}, y^{\mathsf{l}})$ | $Q_{\mathsf{b}}(x^{\mathsf{o}}, y^{\mathsf{o}}, b^{\mathsf{k}}, b^{\mathsf{l}})$ | $E$ |
|---|---:|---:|---:|
| AUSTRIA | 1 | 1 | 1 |
| BELGIUM | 1.3471 | 2.436 | 0.553 |
| CANADA | 4.6521 | 8.64 | 0.5384 |
| DENMARK | 0.7304 | 1.191 | 0.6131 |
| FINLAND | 0.716 | 1.182 | 0.6058 |
| FRANCE | 8.0573 | 8.502 | 0.9477 |
| GREECE | 0.6998 | 1.479 | 0.4732 |
| IRELAND | 0.3318 | 1 | 0.3318 |
| ITALY | 7.3549 | 9.079 | 0.8101 |
| NETHERLA | 1.9898 | 1 | 1.9898 |
| NORWAY | 0.6457 | 1 | 0.6457 |
| PORTUGAL | 0.7537 | 1 | 0.7537 |
| SPAIN | 3.8134 | 1 | 3.8134 |
| SWEDEN | 1.2905 | 1.109 | 1.1633 |
| SWITZERL | 1.1315 | 1 | 1.1315 |
| U.K. | 7.7505 | 12.315 | 0.6293 |
| U.S.A. | 46.17 | 108.386 | 0.426 |
| Mean | 5.0321 | 9.489 | 0.9662 |

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