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Efficiency in Managing the Environment and the Opportunity Cost of Pollution Abatement

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Abstract

Using the directional distance function we study a cross section of 110 countries to examine the efficiency of management of the tradeoffs between pollution and income. The DEA model is reformulated to permit 'reverse disposability' of the bad output. Further, we interpret the optimal solution of the multiplier form of the DEA model as an iso-inefficiency line. This permits us to measure the shadow cost of the bad output for a country that is in the interior, rather than on the frontier of the production possibilities set. We also compare the relative environmental performance of countries in terms of emission intensity adjusted for technical efficiency. Only 10

Keywords: Data Envelopment Analysis, directional distance function, pollution-income tradeoff, shadow price.

EFFICIENCY IN MANAGING THE ENVIRONMENT AND THE OPPORTUNITY COST OF POLLUTION ABATEMENT

In recent years, a lot of attention has been devoted to the importance of improving global environmental quality and restraining the process of global warming. While most share a concern regarding the ecological impact of global warming and its economic consequences, there is at the same time awareness and concern regarding the economic costs that an effort to improve environmental quality might entail for different countries. In 1992, the Framework Convention on Climate Change (FCCC) represented for the first time a voluntary commitment from nations (Annex I countries i.e., industrialized countries) to curb global warming. This was followed by the Kyoto Protocol of 1997, a key aspect of which was to stipulate that the Annex I countries will reduce the emissions of greenhouse gases (GHGs) by 5% of their respective 1990 levels by 2008-2012, thereby assigning "common but differentiated responsibility" for each country.

In a recent study, Nordhaus and Boyer (2000) contend that the Kyoto Protocol is not properly grounded in economics or environmental policy. They consider several alternative policy approaches and through comprehensive analysis they conclude that although in the early years the overall abatement level under the Kyoto Protocol is close to that under an 'optimal program' that they suggest, in the long run the emissions are actually higher under the Protocol approach than under their 'optimal program'. They attribute this to two major shortcomings with the Kyoto Protocol approach: (i) Since each country's emission limit is based on historical levels, it gives a major windfall to countries which historically had inefficient energy systems; and (ii) The Protocol limits the emissions for only a group of countries but does not do so for the non-Annex I countries. This omission is significant since many of the developing countries will experience more rapid increases in emissions and will likely account for the major contributions to global emissions in the future as compared to the industrialized countries.

While cross-country comparison is not relevant for achieving the goals set by the Kyoto Protocol, we believe that efficient management of the tradeoffs between pollution and income requires each country to learn from the best practices of other countries

around the world. In this paper we use Data Envelopment Analysis (DEA) to carry out a comprehensive study of a cross section of 110 countries and construct a best practice 'meta' frontier. Each country is then compared to this best practice frontier to estimate its efficiency in achieving the optimal balance between pollution reduction and growth in income.

In the existing literature, cross country studies on emissions have followed three main streams. One stream focuses on the relationship between emissions and per capita GDP following the environmental Kuznets curve (EKC) theory, after Kuznets (1955).[1] Schurr et al. (1960) proposed that an inverted U-shaped relationship exists between energy use and economic output in the U.S. A large body of literature has been devoted to investigating this topic ever since. The studies in this area address two main questions – (i) is there an inverted U-shaped relationship between income and emissions? (ii) if so, what is the income level at which the turning point occurs? In general, researchers have found that the inverted U-shaped curve exists for *local pollutants* (SO_2, NO_x, and CO) but most studies have not found this in case of *global pollutants* such as CO_2. This is because local pollutants have a direct impact on the population and have, therefore, been regulated. Further, the income elasticity of environmental demand is generally higher in case of local pollutants. Even in cases when the EKC holds, the literature does not provide a consensus view as to the turning point. (see Borghesi, 1999 for a survey of this literature and criticisms of the EKC theory).

Another group of studies have undertaken an index decomposition approach to identify the contribution of explanatory factors beside growth in economic output, such as changes in fuel consumption, share of fossil fuels in energy use, aggregated energy intensity, sectoral fuel share, fuel emission factors, sectoral energy intensity, population and so on, to the changes in emissions over time for each country. Recent studies that have employed this approach in cross-country comparisons include Ang and Zhang (1999), Greening et al. (1998), Luukkanen and Kaivo-oja (2000), Schipper et al. (1997), and Sun and Malaska (1998).

[1] Kuznets (1955) was the first to observe an inverted U-shape relationship between income inequality and a country's aggregate income.

While the EKC literature explores the relationship between changes in the levels of pollution concomitant with the growth in GDP, the index decomposition literature focuses on the sources of pollution intensity. A third stream attempts to account for the good output (GDP) as well as the bad output (pollution), along with resource utilization within the analytical framework. Production of the desirable output (GDP) in an economy leads to the production of the undesirable output (emissions). In general, a nation's pollution abatement efforts entail economic costs by limiting economic growth, and also by diverting investment from productive purposes to abatement purposes.[2] On the other hand there are benefits from such efforts in terms of reduced damages from pollution. Papers in this strand of the literature have utilized the directional distance function approach developed by Chambers et al. (1996). Chung et al. (1997) construct a Malmquist-Luenberger productivity index to isolate the contributions of technical change and technical efficiency change to productivity growth in the Swedish paper and pulp mills which generate both good and bad outputs.[3] Färe et al. (2001) and Weber and Domazlicky (2001) employ the Malmquist-Luenberger index to analyze the manufacturing productivity growth across the states of the U.S., taking into account the emissions that are produced in the process. In an interstate analysis of U.S. agriculture, Färe et al. (2006) use directional distance functions to derive estimates of production inefficiency and shadow prices for polluting outputs. A few papers have used the Malmquist-Luenberger approach in the context of a global cross-country analysis. Jeon and Sickles (2004) analyze productivity growth in OECD and Asian countries over the period 1980 to 1990, taking into account the production of both GDP and CO_2 emissions. Kumar (2006) examines environmentally sensitive total factor productivity growth in 41 developed and developing countries over the period 1971 to 1992 accounting for both GDP and CO_2 emissions.

Our study extends the existing literature in several ways, both methodological and empirical. First, we reformulate the DEA model to permit what we call the '*reverse disposability*' of the bad output. Second, we interpret the optimal solution of the dual or

[2] Porter and van der Linde (1995) argue that environmental protection, properly pursued, can be achieved without any economic costs. Their viewpoint, however, has been strongly criticized (see Palmer et al., 1995).

[3] In an earlier paper Färe et al. (1989) apply graph hyperbolic distance function to obtain efficiency measures for US paper mills in the presence of undesirable outputs.

multiplier form of the relevant DEA model as an *iso-inefficiency* line. This permits us to measure the shadow cost of the bad output for a country that is in the interior, rather than on the frontier of the production possibilities set. In our empirical application, we analyze a bigger dataset of 110 countries as compared to most studies in the literature that focus mainly on cross-country comparison of OECD countries. This extended coverage is of special significance in light of the growing importance of countries like India, Brazil, and China in the world economic scene. Apart from obtaining measures of technical efficiency for each country we compute and compare the opportunity cost of pollution reduction in the form of lost GDP, both for a 1% reduction in each country's pollution as well as for a common target reduction in the absolute amount of pollution equal to 1% of the pollution in the U.S. We also compare the relative environmental performance of countries in terms of emission intensity adjusted for technical efficiency.

Our empirical analysis shows that only 10% of the countries in the sample are on the frontier. Also, there is considerable inter-country variation in the imputed opportunity cost of either a 1% decrease from their actual CO_2 emission levels or of a target reduction of a specific absolute amount of CO_2 reduction. We also find that differences in technical efficiency contribute to a large extent to differences in the observed levels of CO_2 intensity.

The rest of the paper is organized as follows. Section 2 provides the methodological background for the nonparametric analysis. Section 3 develops the DEA models for measuring the directional distance function and the Nerlove-Luenberger measure of technical efficiency. Section 4 presents the findings from the empirical application and section 5 is the conclusion.

2. The Production Technology

Consider an m-output, n-input technology defined by the production possibility set

$$T = \{(x, y): y \text{ can be produced from } x\} \quad (1)$$

Assume further that the output bundle can be partitioned as $y = (g, b)$, where g is the sub-vector of *good* or desirable outputs while b is the sub-vector of *bad* or undesirable outputs. Following the convention in the literature, we assume that all inputs are freely disposable and that the production possibility set is convex.

Further, the *good* outputs are freely disposable. However, the bad outputs are not freely disposable although they are weakly disposable together with the good outputs. These assumptions can be formally stated as follows.

(A1) If $(x^0, g,b) \in T$ and $x^1 \geq x^0$, then $(x^1, g,b) \in T$.

(A2) If $(x^0, g_0,b_0) \in T$ and $(x^1, g_1,b_1) \in T$, then $(\lambda x^0+(1-\lambda)x^1,\lambda g_0+(1-\lambda)g_1,\lambda b_0+(1-\lambda)b_1) \in T$ for all $0 \leq \lambda \leq 1$

(A3). If $(x, g_0,b) \in T$ and $g_1 \leq g_0$, then $(x, g_1,b) \in T$. This implies that the good output is strongly disposable.

(A4). If $(x, g_0,b_0) \in T$, then $(x, kg_0,kb_0) \in T$, for all $0 \leq k \leq 1$. Thus the two outputs are together weakly disposable. Note that the bad output is *not strongly disposable*.

A new assumption that we make in this paper is:

(A5) If $(x, g, b_0) \in T$ and $b_1 \geq b_0$, then $(x, g, b_1) \in T$. This may be characterized as "*reverse disposability*" of the bad output.

This assumption of '*reverse disposability*' of the bad output is essentially similar to the assumption of free disposability of the good output. After all, if a lower level of the desirable output could be associated with the same level of the bad output, a higher level of the bad output could also be generated along side the same level of the good output. Suppose that the good output is mega-watts of electricity generated and the bad output is pollutants emitted into the atmosphere. If a firm manages its pollution control device poorly, it is possible that the pollution level goes up without any increase in power generated.

Under assumptions (A1-A5), the production possibility set constructed from a sample of observed input output bundles (x^j, g_j, b_j) $(j=1,2,\ldots,N)$ will be:

$$T = \left\{ (x;g,b) : x \geq \sum_j \lambda_j x^j; g \leq k(\sum_j \lambda_j g_j); b \geq k(\sum_j \lambda_j b_j); \sum_j \lambda_j = 1; 0 \leq k \leq 1; \lambda_j \geq 0 (j = 1,2,\ldots,N) \right\}. \quad \ldots(2)$$

For any given input bundle x^0, the corresponding output set is

$$P(x^0) = \left\{ (g,b) : x^0 \geq \sum_j \lambda_j x^j; g \leq k(\sum_j \lambda_j g^j); b \geq k(\sum_j \lambda_j b^j); \sum_j \lambda_j = 1; 0 \leq k \leq 1; \lambda_j \geq 0 (j = 1,2,\ldots,N) \right\}. \quad \ldots(2a)$$

For a 1-input, 2-output (1 good and one bad) example, consider the following production possibility set

$$T = \left\{(x; g, b) : \frac{g^2}{b} \leq \sqrt{x}\right\}. \quad (3)$$

Then, for x equal to 3, we have the output set

$$P(x{=}3) = \left\{(g, b) : g^2 \leq \sqrt{3}b\right\}. \quad (3a)$$

It is easy to verify that for this example, whenever any $(g, b) \in P(x{=}3)$, $(kg, kb) \in P(x{=}3)$ for any $k \in (0,1)$.

Further the good and bad outputs are “null joint” in the sense that b can be reduced to zero only if g is also zero. This assumption of *reverse disposability* of the bad output clearly holds for the example shown above.

3. The Directional Distance Function and Nerlove-Luenberger Efficiency

Chambers, Chung, and Färe (1996) introduced the *directional distance function* based on Luenberger’s (1992) *benefit function* to obtain a measure of technical efficiency based on the potential for increasing outputs while reducing inputs simultaneously. Consider some input-output bundle (x^0, y^0) and a reference input-output bundle (z^x, z^y). Then, with reference to the production possibility set, T, the directional distance function can be defined as:

$$\vec{D}(x^0, y^0; z^x, z^y) = \max \ \beta : (x^0 + \beta z^x, y^0 + \beta z^y) \in T. \quad (4)$$

Clearly, the directional distance function evaluated at any specific input-output bundle will depend on (z^x, z^y) as well as on the reference technology. The arbitrarily chosen bundle (z^x, z^y) defines the direction along which the observed bundle, if it is an interior point, is projected on to the efficient frontier of the production possibility set. In the present context, $y^0 = (g_0, b_0)$. Suppose that we choose z^x to be the null vector while $z^y = (g_0, -b_0)$. Then the Directional distance function is

$$\vec{D}(x^0, g_0, b_0; z^x, z^y) = \max \ \beta : (x^0; (1+\beta)g_0, (1-\beta)b_0) \in T. \quad (5)$$

Alternatively,

$$\vec{D}(x^0, g_0, b_0; z^x, z^y) = \max \ \beta : ((1+\beta)g_0, (1-\beta)b_0) \in P(x^0). \quad (5a)$$

The relevant DEA LP problem is

$$\max \quad \beta$$

$$\text{s.t.} \qquad k\left(\sum_{1}^{N}\lambda_j g_j\right) \geq (1+\beta)g_0;$$

$$k\left(\sum_{1}^{N}\lambda_j b_j\right) \leq (1-\beta)b_0; \tag{6}$$

$$\sum_{1}^{N}\lambda_j x^j \leq x^0;$$

$$\sum_{1}^{N}\lambda_j = 1;\ 0 \leq k \leq 1; \lambda_j \geq 0.$$

Defining the weights $\mu_j = k\lambda_j$ we may rewrite this problem as

$$\max \quad \beta$$

$$\text{s.t.} \qquad \sum_{1}^{N}\mu_j g_j - \beta g_0 \geq g_0;$$

$$\sum_{1}^{N}\mu_j b_j + \beta b_0 \leq b_0 \quad; \tag{7}$$

$$\sum_{1}^{N}\mu_j x^j \leq kx^0;$$

$$\sum_{1}^{N}\mu_j = k;\ 0 \leq k \leq 1; \mu_j \geq 0.$$

If we assumed constant returns to scale, the requirement that the λ_js add up to unity would be dropped. In that case, beyond non-negativity there would be no further restrictions on the μ_js. As a result, the variable *k* could be dropped and the input constraints could be replaced by

$$\sum_{1}^{N}\mu_j x^j \leq x^0.$$

The relevant CRS DEA problem would be

$$\max \quad \beta$$

$$\text{s.t.} \qquad \beta g^0 - \sum_{1}^{N}\mu_j g_j \leq -g_0; \tag{8}$$

$$\beta b^0 + \sum_1^N \mu_j b_j \le b_0 \quad ;$$

$$\sum_1^N \mu_j x^j \le x^0 ;$$

$$\mu_j \ge 0.$$

The dual of this LP problem is

$$\min \; w'x^0 + p_b\, b_0 - p_g g_0$$

$$\text{s.t.} \quad w'x^j + p_b\, b_j - p_g g_j \ge 0; \; (j = 1,2,\ldots,N) \tag{9}$$

$$p_g g_0 + p_b\, b_0 = 1;$$

$$w \ge 0; \; p_g, p_b \ge 0.$$

Note that the objective function of this dual problem has a simple interpretation. It is the excess of the total cost consisting of the shadow cost of the inputs and also the shadow cost of the undesired output over the shadow value of the desirable output. By construction, it has a lower bound of zero. That value is realized only when the optimal value of β in the primal problem is zero. In that case, the actual bundle (g_0, b_0) lies on the boundary of $P(x^0)$. Of particular interest is the relative price of the bad output

$$\rho_b = \frac{p_b^*}{p_g^*}, \tag{10}$$

where (p_g^*, p_b^*) is the vector of the optimal values of the shadow prices of the good and the bad output. It shows the required increase in the quantity of the good output that would exactly neutralize the detrimental effect of a marginal increase in the quantity of the bad output without changing the efficiency of the firm. Alternatively, it is the opportunity cost of a marginal decrease in the bad output measured by the allowable decrease in the good output.

4. The Empirical Application

In this paper we analyze cross section data pertaining to 110 countries from the World Resources 2005 data book. The model includes one good output (GDP) and one bad output (CO_2), along with two inputs: fossil fuels (FF) and non-fossil fuels (NFF)

consumed. All inputs and output quantities are measured per capita.[4] GDP per capita is in purchasing power parity adjusted 2002 international dollars[5]. Carbon dioxide emission (CO_2) is measured in metric tons of emission per person in 2000[6]. Both fossil fuels (FF) and non-fossil fuels (NFF) are measured in kilograms of oil equivalent consumed per person in 2001[7]. The summary statistics of the data are reported in Table 1. Not surprisingly, the country with the lowest per capita GDP, Tanzania, is one of the four countries with the lowest level of CO_2 emission. The other three countries tied with Tanzania at the minimum level of CO_2 emission are Congo Democratic Republic, Mozambique, and Nepal, ranked respectively, at 2nd, 9th, and 10th from the bottom in terms of per capita GDP. At the other extreme, Kuwait has the maximum level of CO_2 emission per capita. The lowest and the highest levels of fossil fuels consumption per capita are found in Congo Democratic Republic and Singapore, respectively. Three Middle Eastern countries, Oman, Saudi Arabia, and Kuwait, reported zero consumption of non-fossil fuels. At the other end, Iceland had a level of non-fossil fuel consumption that was about 17 times the average per capita consumption across all countries in this data set. In fact, the share of fossil fuels in total energy consumption was 27.1% in Iceland compared to 79.5% for the World as a whole.

Table 2 reports the CO_2 intensity (in metric tons per $ GDP), which is a commonly used measure of the efficiency with which a country produces its GDP in an environmentally friendly manner. The energy intensity as well as the fossil fuel intensity (both measured in kgoe per $ GDP) are also reported for each country. As is to be expected, the correlation between CO_2 intensity and fossil fuel intensity is much higher (0.9702) than the correlation coefficient between CO_2 intensity and overall energy intensity (0.6594). The average CO_2 intensity for our sample was 0.000502 but ranged from a high of 0.00295 for Uzbekistan to a low of 0.0000724 for Nepal. The average CO_2 intensity for the Annex I countries in our sample was 0.000287, whereas for the non-Annex I countries it was 0.000444.

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[4] Measuring the outputs and inputs per capita obviates the need for including labor as an additional input. Further, we assume that the level of energy use is proportional to the use of capital. This permits us to exclude capital as a separate input from the model.
[5] For an explanation of data construction see page 190 of World Resources 2005.
[6] See page 206 of World Resources 2005.
[7] See page 202 of World Resources 2005.

The main results from the DEA models are also shown in Table 2. The column β^* lists the optimal values of the output-oriented directional distance function showing the proportion by which the good output (GDP per capita) could be expanded while at the same time the bad output (CO_2 emission per capita) be reduced for the individual countries in the sample. It takes the value 0 for 11 countries (namely, Paraguay, Congo Democratic Republic, Algeria, Nepal, Morocco, Bangladesh, Ireland, Costa Rica, Oman, Mozambique, and Cameroon). All of these countries are operating at full efficiency in the sense that it is not possible to increase GDP per capita and reduce pollution at the same time. Ireland is the only country from the developed world that makes this list. Among the rest, Oman is an oil exporting country from the Middle East and the others are all developing economies with moderate to low GDP per capita. Compared with the U.S. (ranked at the 72nd position in the overall list), Ireland has a somewhat higher GDP and a substantially lower rate of CO_2 emission (only 55% of the emission rate of the U.S.), per capita. The case of Oman is also interesting in that it is found to be efficient even though its entire energy consumption comes from fossil fuels. By contrast, Saudi Arabia also uses only fossil fuels but it has a lower per capita GDP and nearly one-third higher CO_2 emissions than Oman. The value of β^* shows that it should be possible for Saudi Arabia to simultaneously reduce emissions and increase per capita GDP by about 13%. Most of the countries in the efficient list are low on overall energy intensity of GDP (Bangladesh, Morocco, Costa Rica, Uruguay, and Ireland) or fossil fuel intensity of GDP (Congo Democratic Republic, Mozambique, Nepal, Cameroon, Costa Rica, and Bangladesh).

Out of the 110 countries in the sample, 70 have optimal values of β^* in excess of 0.33. This implies that it should be possible for each of these countries to simultaneously increase per capita GDP and lower CO_2 emissions by at least 33%. In fact, β^* exceeds 50% for 48 countries. Surprisingly, India and China with lower values of β^* are more efficient than New Zealand, Belgium, and Finland. Among the developed nations of the West, Canada performs the worst with a value of β^* as high as 0.66. In fact, the U.S. barely outperforms countries like Pakistan and India. Not surprisingly, the worst five performers (Bulgaria, Tajikistan, Russian Federation, Uzbekistan, and Ukraine) are all from the former Soviet Bloc.

For the 99 countries with the values of β^* greater than zero, there is no immediate trade off between pollution reduction and producing higher output. For each of these countries, there is room to increase GDP and reduce CO_2 emissions *simultaneously.*[8] Consider the case of Japan for a specific example. The value of β^* (from problem (8) above) for Japan was 0.3192. This implies that it should be possible to increase per capita GDP and, at the same time, reduce CO_2 emissions by 31.92 per cent. This amounts to an increase in GDP per capita by 8598.29 dollars and a decrease in CO_2 emissions per capita by 3.06432 tons without any increase in the inputs. Once such potential increase in GDP and decrease in pollution have been achieved, any further decrease in pollution without increase in the inputs would require a decrease in GDP.

The columns p_g and p_b show the shadow prices of the good output (per capita GDP) and the bad output (per capita CO_2 emissions), respectively. The relative shadow price of CO_2 emissions is shown in the column rp_b. Because actual per capita GDP is expressed in international dollars, rp_b is an opportunity cost of a marginal decrease in emissions per capita expressed in dollars. These shadow prices and the implied opportunity cost of pollution abatement in the form of GDP reduction are really applicable only at the optimal projection of the actual outputs (good and bad) on to the frontier of the production possibility set. It should be recognized, however, that eliminating technical inefficiencies could involve major adjustment costs and may be difficult to achieve in the short run. Thus, the optimal projection serves more as a benchmark for improvement than as an achievable goal in the short term. Even when a country is inefficient and the observed output bundle lies in the interior of the output set of its observed input bundle, *at the existing level of (in)efficiency*, the relative shadow price does provide a measure of the opportunity cost of a marginal reduction in pollution. Note that by standard duality results relating the optimal solutions of the primal and dual LP problems (8) and (9),

$$\frac{\partial \beta^*}{\partial b_0} = p_b^* \text{ and } \frac{\partial \beta^*}{\partial g_0} = -p_g^*. \qquad (11)$$

[8] Based on several case studies, Porter and van der Linde (1995) argue that companies may be able to reduce pollution and at the same time increase their competitiveness by removing resource inefficiencies and realizing potential technological improvements. Our findings at the country level also suggests that most countries in our sample could experience a reduction in pollution along with increase in GDP to a certain extent before facing a tradeoff between the two goals.

With β^* and x^0 held constant,

$$\frac{\partial\beta^*}{\partial b_0}db_0 + \frac{\partial\beta^*}{\partial g_0}dg_0 = p_b^* db_0 - p_g^* dg_0 = 0. \qquad (12)$$

Hence, along the *iso-inefficiency* curve, $\beta^* = w^{*'} x^0 + p_b^* b_0 - p_g^* g_0$,

$$dg_0 = \frac{p_b^*}{p_g^*} db_0. \qquad (13)$$

This last expression defines the minimum reduction in the good output that would be required in order to reduce the bad output by a small amount db_0, unless there is an improvement in technical efficiency. In this sense, it is the opportunity cost of lowering the bad output by db_0.

We now look at the individual shadow prices of GDP and CO_2 emissions and also the relative shadow prices of CO_2 for the different countries in our sample reported in Table 2. The shadow price of GDP (p_g) was positive for each and every observation in the data. However, the shadow price, p_b (and hence the relative price, rp_b) of CO_2 was zero for 7 of the 110 countries. Five of these 7 countries were on the frontier with the value of β^* equal to 0. For every country *j* that was efficient, the optimal solution of the primal problem (8) had β^* equal to 0 and the corresponding λ_j^* equal to 1 with all other variables taking the value 0. Thus, they all exhibited *primal degeneracy*. It is well known that in such cases, the optimal values of the dual variables will be non-unique even when they are non-zero and cannot be interpreted as shadow prices (Ali 1994, Gal 1986)[9]. Thus, we cannot say anything about the opportunity cost of pollution abatement in the case of the 11 countries that showed no technical inefficiency. This is true even for countries like Algeria, Bangladesh, Oman, Mozambique, and Cameroon, all of which had strictly positive values of both of the dual variables. For the two countries that were inefficient but had zero shadow prices of CO_2 emissions (Peru and Uruguay), the pollution constraint was non-binding at the optimal solution. This implies that they would be able to reduce pollution without sacrificing GDP up to the extent of the respective slacks in the constraint. For the remaining 99 countries, both shadow prices are positive

[9] A parametric specification (e.g. Färe et al. 2006) of the distance function could minimize, although not entirely eliminate, the incidence of zero shadow prices.

and the relative shadow price of CO_2 does represent the (marginal) opportunity cost of pollution abatement.

It may be noted in this context, that Jeon and Sickles (2004) did explicitly recognize that the shadow prices were valid only for frontier observations and there could be significant adjustment cost of projecting an actual observation on to the frontier. In an attempt to circumvent this problem, they focused only on the shadow prices of the OECD countries in their sample, the bulk of which they found to be close to the frontier. By contrast, our approach allows us to measure and interpret the shadow price of CO_2 emission of countries without projecting them to the frontier.

A simple interpretation of the relative price of CO_2 emission is that it represents the minimum reduction in GDP per capita necessary for lowering per capita emissions by 1 metric ton. Alternatively, it shows the amount by which per capita GDP would have to rise to justify an increase in per capita emissions by 1 ton, unless the country can increase its efficiency. By this measure, a 1-ton decrease in CO_2 emission in the U.S. would require a decrease in per capita GDP by $3140.04 where as a similar decline in pollution in India would require a sacrifice in per capita GDP of $7940.03. But this line of reasoning fails to consider the fact that a 1-ton change is less than a 5% change from the observed level of emission in the U.S. By contrast, it is a 100% change in the case of India. Instead of considering the same absolute amount of change in emissions across different countries, it would be more meaningful to consider the opportunity cost of the same percentage change from the observed levels of emission. In Table 3 we compare the opportunity costs (in the form of foregone GDP per capita) of a 1% reduction in CO_2 emission per capita for a sample of 12 countries. The column PC_CO_2 reports the actual levels of emission per capita in the selected countries. The column (ΔCO_2) shows the actual quantities of CO_2 that constitute 1% of the respective observed emission levels. Note that 1% of actual emission per capita in the U.S. is 0.202 metric ton. In the case of China it is only 0.027 ton and for India it is even lower (0.01 ton). The final column (OC_GDP) shows the opportunity cost of a 1% reduction in CO_2 emission expressed as the percentage of the actual per capita GDP in these countries. In the U.S, Brazil, China, and Korea a 1% decrease (increase) in emission per capita would be offset by about 1.8% decrease (increase) in per capita GDP. For Canada a 1% change in emission would

warrant a 4.5% change in GDP. For the Russian Federation a 1% decrease or increase in emission would be offset by a 4% change in GDP in the same direction. For Germany (1.18%), Japan (1.12%), Argentina (1.05%), and Mexico (1.36%) the opportunity cost in terms of GDP change is much lower.

It is sometimes argued that developed industrial nations like the U.S. would have to bear the bulk of the cost of pollution abatement because a 1% reduction from their existing levels of emission would imply a much larger *absolute level* of reduction. After all, CO_2 pollution is a global phenomenon and a specific quantity of emission whether from the U.S. or from China would in the end have the same impact on the global environment. In Table 4 we evaluate the opportunity cost of the same target level of pollution abatement to different countries. Note that the countries differ in the levels of per capita emission as well as their population sizes. We selected a target level of reduction in total quantity of emission equal to 1% of the total emission level observed in the U.S. in 2000. A per capita CO_2 emission level of 20.2 tons and a 2000 population size of 283 millions yields a total emission figure of 5,716.6 million metric tons in the U.S. in the year 2000. Hence, a 1% emission reduction implies a targeted level of reduction of 57.166 million metric tons. The same absolute amount of reduction is a much lower per capita reduction in countries with large population sizes like China and India compared to countries like Canada or Argentina where the population size is much smaller. Because of differences in the population sizes, the same amount of 57.166 ton reduction in total CO_2 emission translates into a 1.844 ton reduction *per capita* in Canada but only a 0.0566 ton reduction *per capita* in India (see column (7)). The column 'ΔCO_2_%' shows the implied reduction as percentage of the actual emissions. We use the country specific shadow relative price of CO_2 reduction to figure out the implied opportunity cost of this reduction for each of the selected countries. The final column 'OC_GDP' shows the resulting decline in GDP per capita that would be needed to achieve this absolute reduction in total emission in the individual countries. As can be seen from the last column in Table 4, a 1% decrease in per capita emission in the U.S. would require a 1.774% reduction in GDP per capita. But the same amount of emission reduction will cost 49.66% reduction in per capita GDP in Canada, 41.119% loss of GDP in South Africa, 3.075% loss in China, and 16.779% reduction in per capita GDP in India. It is, therefore, difficult to argue that a

country like the U.S. would have to bear the bulk of the cost of global pollution abatement.

Because the environmental performance of a country is often evaluated in terms of pollution intensity of the output produced, it is worthwhile to examine the relative performance of countries once their actual output has been projected on to the efficient frontier. The last column of Table 2 provides the technical efficiency adjusted CO_2 intensity ($CO_2^* y^*$). A country's CO_2 intensity depends on the composition of its GDP (which in turn often depends upon its stage of economic development), the available sources of energy in the form of fossil or non-fossil fuel, and its efficiency in utilizing its resources in producing the output with the least damage to the environment. A country which is low in CO_2 intensity is often perceived to be environmentally efficient. A different picture of the relative performance often emerges when we examine the technical efficiency adjusted CO_2 intensity. This measure shows the relative position of each country based on its core CO_2 intensity i.e., performance that is purged of the effect of resource use inefficiency. In this context it is interesting to consider the case of the Russian Federation and Ukraine. In our sample these two countries are ranked 105th and 107th respectively, in terms of CO_2 intensity, whereas their ranks are 54th and 33rd respectively, in terms of technical efficiency adjusted emission intensity. This implies that the *core* emission intensities of these countries are not as high relative to other countries. It is primarily the resource utilization inefficiency that leads to such poor environmental performance of these countries. For our sample the rank correlation between the unadjusted and adjusted emission intensities was 0.5632 implying that in addition to *core* emission intensity, differences in technical inefficiency is an important determinant of the environmental performance across countries.

The main findings of this study can now be summarized as follows:

- For most countries in our sample it would be possible to produce a higher level of GDP and a lower level of pollution from their input bundles if they can improve their technical efficiency.
- Of the eleven countries found to be on the frontier of the production possibilities set, Ireland is the only country from the developed world that makes this list.

- There is considerable variation across countries in the opportunity cost of a 1% reduction in CO_2 emission per capita. In the U.S., Brazil, China, and Korea a 1% decrease in emission per capita would entail about 1.8% decrease in per capita GDP whereas in case of Canada and the Russian Federation it would require a 4.5% and 4% reduction in GDP.
- Whereas a 1% decrease in CO_2 in the U.S. would cost 1.8% of GDP per capita, the same absolute volume of CO_2 reduction would have an opportunity cost of 43% loss of GDP per capita in Argentina, nearly 50% in Canada, and 41% in South Africa. It is therefore, difficult to argue that the U.S. would have to bear a disproportionate share of the cost of pollution reduction.
- A comparison of the actual and the technical efficiency adjusted emission intensities reveals the important role of variation in technical efficiency in explaining the relative environmental performance of a country. Selected poor performing countries like the Russian Federation and Ukraine would improve significantly in the ranking through better resource utilization.

5. Conclusion

This paper uses DEA to measure technical efficiency of production where GDP and CO_2 emissions are the good and the bad output, using the directional distance function as the analytical framework. We also derive the relative shadow price of the bad output, measuring the opportunity cost of a marginal reduction in CO_2 emission in the form of a reduction in GDP per capita. One caveat is that many of the countries found to be technically efficient are found to be from the less developed parts of the world with low levels of industrialization. Because the extent of energy use is tied to the use of capital and therefore to the state of industrial efficiency, their measured level of efficiency might simply reflect the less developed state of their economy.

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Table 1: Summary Statistics

Variable	Mean	Std Deviation	Min	Max
GDP (per capita PPP int’l $ 2002)	10420.19	9875.296664	579 Tanzania	36596 Norway
CO2 (metric tons per person 2000)	4.891818	4.863652421	0.1 *	26 Kuwait
fossil fuel (per capita kgoe 2001)	1712.492	1720.182095	13.29 Congo Dem Rep	7088.79 Singapore
non fossil fuel (per capita kgoe 2001)	505.581	971.2016737	0 **	8602.2 Iceland

* Congo Democratic Republic, Mozambique, Nepal, Tanzania
** Kuwait, Oman, Saudi Arabia
Source: World Resources, 2005.

Table 2: Data Characteristics and DEA Results by Country

N	Country	GDP	CO_2	FF	NFF	CO_2Int	FFInt	EnerInt	β	p_g	p_b	rp_b	CO2*y*
	Asia (excl. Middle East)												
1	Armenia	3117	1.2	559.49	184.51	0.000385	0.1795	0.23869	0.5351	0.000079	0.6279	7940.03	0.000117
2	Azerbaijan	3207	3.6	1386.88	21.12	0.001123	0.43245	0.43904	0.5860	0.000069	0.2164	3140.04	0.000293
3	Bangladesh	1695	0.2	89.47	55.54	0.000118	0.05278	0.08555	0.0000	0.000305	2.4185	7940.03	0.000118
4	China	4577	2.7	697.18	189.82	0.00059	0.15232	0.1938	0.5782	0.000077	0.2405	3140.04	0.000158
5	Georgia	2307	1.2	240.7	221.3	0.00052	0.10433	0.20026	0.6462	0.000084	0.6709	7940.03	0.000112
6	India	2681	1	304.8	209.2	0.000373	0.11369	0.19172	0.5331	0.000094	0.7476	7940.03	0.000114
7	Indonesia	3228	1.4	470.68	240.32	0.000434	0.14581	0.22026	0.5822	0.000070	0.5535	7940.03	0.000115
8	Japan	26937	9.6	3309.62	781.38	0.000356	0.12287	0.15187	0.3192	0.000018	0.0550	3140.04	0.000184
9	Kazakhstan	5814	7.9	2528.5	67.5	0.001359	0.4349	0.44651	0.6626	0.000033	0.1026	3140.04	0.000276
10	Korea, Rep	17161	10	3454.35	677.65	0.000583	0.20129	0.24078	0.5613	0.000021	0.0647	3140.04	0.000164
11	Kyrgyzstan	1622	1	264.18	182.82	0.000617	0.16287	0.27559	0.6976	0.000105	0.8304	7940.03	0.00011
12	Malaysia	9130	5.4	2069.57	127.43	0.000591	0.22668	0.24064	0.3939	0.000038	0.1204	3140.04	0.000257
13	Nepal	1382	0.1	44.8	305.2	7.24E-05	0.03242	0.25326	0.0000	0.000362	5.0000	13820	7.24E-05
14	Pakistan	1941	0.7	261.51	179.49	0.000361	0.13473	0.2272	0.5285	0.000133	1.0588	7940.03	0.000111
15	Philippines	4171	1	295.39	250.61	0.00024	0.07082	0.1309	0.3511	0.000083	0.6556	7940.03	0.000115
16	Singapore	24006	15.2	7088.79	14.21	0.000633	0.29529	0.29588	0.1887	0.000018	0.0373	2069	0.000432
17	Sri Lanka	3560	0.6	184.85	238.15	0.000169	0.05192	0.11882	0.0902	0.000280	0.0045	15.88	0.000141
18	Tajikistan	981	0.7	278.62	215.38	0.000714	0.28402	0.50357	0.7634	0.000153	1.2143	7940.03	9.57E-05
19	Thailand	7009	2.8	1004.91	222.09	0.000399	0.14337	0.17506	0.3829	0.000063	0.1987	3140.04	0.000178
20	Uzbekistan	1661	4.9	1976.99	24.01	0.00295	1.19024	1.2047	0.8322	0.000059	0.1842	3140.04	0.00027
21	Viet Nam	2305	0.6	187.87	309.13	0.00026	0.08151	0.21562	0.4321	0.000141	1.1232	7940.03	0.000103
	Europe												
22	Albania	4270	1	361.24	187.76	0.000234	0.0846	0.12857	0.3302	0.000082	0.6503	7940.03	0.000118
23	Austria	29220	7.9	2937.25	852.75	0.00027	0.10052	0.12971	0.2216	0.000019	0.0581	3140.04	0.000172
24	Belarus	5518	5.9	2266.52	178.49	0.001069	0.41075	0.4431	0.6836	0.000042	0.1306	3140.04	0.000201
25	Belgium	27569	12.2	4393.4	1349.6	0.000443	0.15936	0.20831	0.5566	0.000015	0.0477	3140.04	0.000126
26	Bosnia and Herzegovina	5777	3.6	943.36	128.64	0.000623	0.1633	0.18556	0.4683	0.000059	0.1838	3140.04	0.000226
27	Bulgaria	7253	5.5	1776.79	647.21	0.000758	0.24497	0.33421	0.7396	0.000020	0.1559	7940.03	0.000113
28	Croatia	10286	4.3	1530.86	247.14	0.000418	0.14883	0.17286	0.3348	0.000042	0.1320	3140.04	0.000208

N	Country	GDP	CO_2	FF	NFF	CO_2Int	FFInt	EnerInt	β	p_g	p_b	rp_b	CO2*y*
29	Czech Rep	15794	12.1	3656.62	379.38	0.000766	0.23152	0.25554	0.5483	0.000019	0.0584	3140.04	0.000224
30	Denmark	30943	9.6	3287.22	418.78	0.00031	0.10623	0.11977	0.1186	0.000016	0.0514	3140.04	0.000244
31	Estonia	12255	10.9	3114.38	357.62	0.000889	0.25413	0.28331	0.6205	0.000022	0.0676	3140.04	0.000208
32	Finland	26186	10.9	3708.74	2809.3	0.000416	0.14163	0.24891	0.5834	0.000009	0.0704	7940.03	0.00011
33	France	26921	6.1	2403.4	2055.6	0.000227	0.08928	0.16563	0.3381	0.000013	0.1054	7940.03	0.000112
34	Germany	27102	10.2	3585.18	677.82	0.000376	0.13228	0.15729	0.3036	0.000017	0.0531	3140.04	0.000201
35	Greece	18718	8.5	2477.79	144.21	0.000454	0.13237	0.14008	0.2366	0.000022	0.0692	3140.04	0.00028
36	Hungary	13869	5.7	2102.23	439.77	0.000411	0.15158	0.18329	0.3928	0.000031	0.0989	3140.04	0.000179
37	Iceland	29749	7.9	3197.8	8602.2	0.000266	0.10749	0.39665	0.5358	0.000011	0.0859	7940.03	8.03E-05
38	Ireland	36360	11.2	3813.98	62.02	0.000308	0.10489	0.1066	0.0000	0.000028	0.0000	0	0.000308
39	Italy	26429	7.8	2747.81	242.19	0.000295	0.10397	0.11313	0.0534	0.000020	0.0617	3140.04	0.000265
40	Latvia	9202	2.7	1120.56	707.44	0.000293	0.12177	0.19865	0.4438	0.000033	0.2591	7940.03	0.000113
41	Lithuania	10313	3.3	1342.65	960.35	0.00032	0.13019	0.22331	0.4858	0.000027	0.2175	7940.03	0.000111
42	Macedonia, FYR	6483	4.4	1152.52	129.48	0.000679	0.17778	0.19775	0.4838	0.000049	0.1547	3140.04	0.000236
43	Moldova, Rep	1478	1.6	676.01	57.99	0.001083	0.45738	0.49662	0.7167	0.000154	0.4829	3140.04	0.000179
44	Netherlands	29105	11	4589.45	241.55	0.000378	0.15769	0.16599	0.1583	0.000016	0.0493	3140.04	0.000275
45	Norway	36596	7.9	3215.1	2705.9	0.000216	0.08785	0.16179	0.3156	0.000010	0.0799	7940.03	0.000112
46	Poland	10934	7.9	2239.91	103.09	0.000723	0.20486	0.21429	0.4436	0.000028	0.0879	3140.04	0.000279
47	Portugal	18282	6.5	2124.83	340.17	0.000356	0.11623	0.13483	0.2239	0.000026	0.0812	3140.04	0.000225
48	Romania	6556	4	1421.97	220.03	0.00061	0.2169	0.25046	0.5352	0.000052	0.1643	3140.04	0.000185
49	Russian Federation	8269	10.6	3898.7	390.3	0.001282	0.47148	0.51868	0.7825	0.000024	0.0756	3140.04	0.000156
50	Slovakia	12892	6.9	2543.51	926.49	0.000535	0.19729	0.26916	0.6454	0.000015	0.1173	7940.03	0.000115
51	Slovenia	18615	7.6	2435.52	1004.5	0.000408	0.13084	0.1848	0.5530	0.000013	0.1006	7940.03	0.000118
52	Spain	21457	7.5	2502.15	613.85	0.00035	0.11661	0.14522	0.3086	0.000022	0.0698	3140.04	0.000185
53	Sweden	26048	5.5	1987.89	3774.1	0.000211	0.07632	0.22121	0.3571	0.000014	0.1139	7940.03	0.0001
54	Switzerland	30008	5.8	2308.45	1597.6	0.000193	0.07693	0.13017	0.2514	0.000013	0.1044	7940.03	0.000116
55	Ukraine	4887	7	2446.94	425.06	0.001432	0.5007	0.58768	0.8519	0.000017	0.1313	7940.03	0.000115
56	United Kingdom	26155	9.5	3534.69	459.31	0.000363	0.13514	0.15271	0.2233	0.000018	0.0561	3140.04	0.000231
	Middle East & N. Africa												
57	Algeria	5783	2.5	954.13	2.87	0.000432	0.16499	0.16549	0.0000	0.000091	0.1889	2069	0.000432
58	Egypt	3813	1.9	658.17	36.84	0.000498	0.17261	0.18227	0.2925	0.000102	0.3211	3140.04	0.000273

N	Country	GDP	CO_2	FF	NFF	CO_2Int	FFInt	EnerInt	β	p_g	p_b	rp_b	CO2*y*
59	Iran, Islamic Rep	6701	4.5	1767.15	17.85	0.000672	0.26371	0.26638	0.3731	0.000048	0.1507	3140.04	0.000307
60	Israel	19532	10.4	3350.61	82.39	0.000532	0.17154	0.17576	0.2818	0.000019	0.0602	3140.04	0.000298
61	Jordan	4223	3.1	968.25	18.75	0.000734	0.22928	0.23372	0.4207	0.000072	0.2250	3140.04	0.000299
62	Kuwait	16320	26	6956	0	0.001593	0.42623	0.42623	0.3776	0.000019	0.0265	1389.27	0.00072
63	Lebanon	4755	4.5	1460.15	76.85	0.000946	0.30708	0.32324	0.5746	0.000053	0.1663	3140.04	0.000256
64	Morocco	3810	1.1	349.31	22.69	0.000289	0.09168	0.09764	0.0000	0.000262	0.0000	0	0.000289
65	Oman	13337	9.6	3714	0	0.00072	0.27847	0.27847	0.0000	0.000037	0.0521	1389.27	0.00072
66	Saudi Arabia	12845	12	4844	0	0.000934	0.37711	0.37711	0.1296	0.000034	0.0471	1389.27	0.00072
67	Syrian Arab Rep	3527	3.1	771.04	50.96	0.000879	0.21861	0.23306	0.5419	0.000075	0.2368	3140.04	0.000261
68	Tunisia	6763	2.1	725.02	131.98	0.000311	0.1072	0.12672	0.1772	0.000075	0.2351	3140.04	0.000217
69	Turkey	6365	3.3	905.84	140.16	0.000518	0.14232	0.16434	0.4000	0.000060	0.1877	3140.04	0.000222
70	Yemen	870	0.6	186.8	4.2	0.00069	0.21471	0.21954	0.3975	0.000363	1.1402	3140.04	0.000297
	Sub-Saharan Africa												
71	Angola	2208	0.4	200.59	461.41	0.000181	0.09085	0.29982	0.3449	0.000186	1.4747	7940.03	8.82E-05
72	Cameroon	2037	0.2	68.13	349.87	9.82E-05	0.03345	0.2052	0.0000	0.000443	0.4920	1111.53	9.82E-05
73	Congo	979	0.2	76.8	186.2	0.000204	0.07845	0.26864	0.3770	0.000390	3.0931	7940.03	9.24E-05
74	Congo, Dem Rep	621	0.1	13.29	288.71	0.000161	0.0214	0.48631	0.0000	0.001610	0.0000	0	0.000161
75	Côte d'Ivoire	1520	0.5	131.3	272.7	0.000329	0.08638	0.26579	0.5420	0.000182	1.4463	7940.03	9.77E-05
76	Gabon	6595	1.2	529.47	797.53	0.000182	0.08028	0.20121	0.2772	0.000062	0.4925	7940.03	0.000103
77	Ghana	2141	0.3	108.12	299.88	0.00014	0.0505	0.19057	0.1748	0.000321	1.0401	3236.95	9.84E-05
78	Kenya	1018	0.3	87.62	407.39	0.000295	0.08607	0.48626	0.6057	0.000194	2.6762	13820	7.24E-05
79	Mozambique	1061	0.1	25.32	396.68	9.43E-05	0.02386	0.39774	0.0000	0.000943	0.0000	0	9.43E-05
80	Namibia	6128	1	393.66	207.35	0.000163	0.06424	0.09808	0.1074	0.000108	0.3388	3140.04	0.000132
81	Nigeria	919	0.4	177.39	632.61	0.000435	0.19303	0.88139	0.7149	0.000155	2.1436	13820	7.24E-05
82	Senegal	1594	0.4	146.85	183.15	0.000251	0.09213	0.20703	0.4056	0.000210	1.6646	7940.03	0.000106
83	South Africa	10152	7.8	2074.23	351.77	0.000768	0.20432	0.23897	0.6090	0.000029	0.0906	3140.04	0.000187
84	Sudan	1936	0.2	79.57	341.43	0.000103	0.0411	0.21746	0.0794	0.000387	1.2530	3236.95	8.81E-05
85	Tanzania, United Rep	579	0.1	26.98	364.02	0.000173	0.0466	0.6753	0.4095	0.000510	7.0474	13820	7.24E-05
86	Zambia	839	0.2	62.02	545.98	0.000238	0.07392	0.72467	0.5343	0.000278	3.8357	13820	7.24E-05
	North America												
87	Canada	29484	16.9	6159.23	1839.8	0.000573	0.2089	0.2713	0.6614	0.000006	0.0485	7940.03	0.000117
88	United States	35746	20.2	6827.9	1093.1	0.000565	0.19101	0.22159	0.4909	0.000010	0.0317	3140.04	0.000193

N	Country	GDP	CO_2	FF	NFF	CO_2Int	FFInt	EnerInt	β	p_a	p_b	rp_b	CO2*y*
	C. America & Caribbean												
89	Costa Rica	8817	1.3	440.44	426.56	0.000147	0.04995	0.09833	0.0000	0.000113	0.0018	15.88	0.000147
90	Dominican Rep	6644	2.4	745.2	174.8	0.000361	0.11216	0.13847	0.2998	0.000071	0.2214	3140.04	0.000195
91	El Salvador	4887	1.1	302.17	373.83	0.000225	0.06183	0.13833	0.2821	0.000166	0.1722	1037.82	0.000126
92	Guatemala	4058	0.9	278.93	345.07	0.000222	0.06874	0.15377	0.3350	0.000089	0.7087	7940.03	0.00011
93	Honduras	2597	0.8	253.3	235.7	0.000308	0.09754	0.18829	0.4703	0.000112	0.8873	7940.03	0.000111
94	Jamaica	3982	4	1353.66	186.34	0.001005	0.33994	0.38674	0.7350	0.000060	0.1898	3140.04	0.000153
95	Mexico	8972	3.9	1338.63	177.37	0.000435	0.1492	0.16897	0.3149	0.000047	0.1480	3140.04	0.000226
96	Nicaragua	2486	0.7	240.58	296.42	0.000282	0.09677	0.21601	0.4529	0.000124	0.9871	7940.03	0.000106
97	Panama	6166	1.9	834.76	223.24	0.000308	0.13538	0.17159	0.3371	0.000082	0.2588	3140.04	0.000153
98	Trinidad and Tobago	9446	14	6697.85	20.15	0.001482	0.70907	0.7112	0.6197	0.000026	0.0539	2069	0.000348
	South America												
99	Argentina	11083	3.7	1317.03	217.97	0.000334	0.11883	0.1385	0.2081	0.000044	0.1383	3140.04	0.000219
100	Bolivia	2459	1.4	397.66	106.34	0.000569	0.16172	0.20496	0.5806	0.000146	0.4581	3140.04	0.000151
101	Brazil	7752	1.9	641.59	422.41	0.000245	0.08276	0.13725	0.3568	0.000044	0.3477	7940.03	0.000116
102	Chile	9796	3.6	1148.74	395.26	0.000367	0.11727	0.15762	0.4314	0.000047	0.1488	3140.04	0.000146
103	Colombia	6493	1.5	497.22	185.78	0.000231	0.07658	0.10519	0.1589	0.000101	0.2306	2288.36	0.000168
104	Ecuador	3583	1.7	585.43	106.57	0.000474	0.16339	0.19313	0.4262	0.000112	0.3520	3140.04	0.000191
105	Paraguay	4657	0.7	186.26	483.74	0.00015	0.04	0.14387	0.0000	0.000215	0.0000	0	0.00015
106	Peru	5012	1.1	313.96	145.04	0.000219	0.06264	0.09158	0.0430	0.000200	0.0000	0	0.000201
107	Uruguay	7767	1.9	474.57	328.43	0.000245	0.0611	0.10339	0.1711	0.000129	0.0000	0	0.000173
108	Venezuela	5368	5.6	1983.32	232.68	0.001043	0.36947	0.41282	0.7270	0.000044	0.1368	3140.04	0.000165
	Oceania												
109	Australia	28262	17.4	5628.45	346.55	0.000616	0.19915	0.21141	0.3985	0.000012	0.0379	3140.04	0.000265
110	New Zealand	21742	8.6	3370.89	1424.1	0.000396	0.15504	0.22054	0.5475	0.000011	0.0882	7940.03	0.000116
	Mean	**10420**	**4.892**	**1712.49**	**505.58**	**0.000502**	**0.1738**	**0.25613**	**0.3882**	**0.0001148**	**0.51204**	**4732.01**	**0.000189**
	Std Dev	**9920.5**	**4.886**	**1728.05**	**975.65**	**0.000397**	**0.15273**	**0.17138**	**0.2221**	**0.0001949**	**1.0079**	**3297.68**	**0.000118**

Table 3: Opportunity cost of 1% pollution reduction for selected countries

(1)	(2)	(3)	(4)	(5)	(6)
No	**Country**	**PC_CO_2**	**PC_GDP**	**ΔCO_2**	**OC_GDP**
1	United States	20.2	35746	0.202	1.7744
2	Canada	16.9	29484	0.169	4.5512
3	Germany	10.2	27102	0.102	1.1818
4	Russian Federation	10.6	8269	0.106	4.0252
5	Japan	9.6	26937	0.096	1.1191
6	Argentina	3.7	11083	0.037	1.0483
7	Brazil	1.9	7752	0.019	1.9461
8	China	2.7	4577	0.027	1.8523
9	India	1	2681	0.01	2.9616
10	Korea	10	17161	0.1	1.8298
11	Mexico	3.9	8972	0.039	1.3649
12	South Africa	7.8	10152	0.078	2.4126

Note: For each country, column (3) and (4) report the per capita CO_2 emission in metric tons (2000) and per capita GDP in PPP International $ (2002) respectively. Column (5) reports in metric tons the equivalent of a 1% reduction in per capita CO_2 emission. Column (6) reports the opportunity cost of a 1% reduction in per capita CO_2 emission in terms of forgone per capita GDP in %.

Table 4: Opportunity cost of a target pollution reduction amount for selected countries

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
No	**Country**	**PC_CO_2**	**Pop**	**Total CO_2**	**GDP**	**Target ΔPC_CO_2**	**$\Delta CO_2\_\%$**	**OC_GDP**
1	U.S.	20.2	283	5716.6	35746	0.202	**1**	1.77443
2	Canada	16.9	31	523.9	29484	1.8440645	10.91162	49.66059
3	Germany	10.2	82	836.4	27102	0.6971463	6.83477	8.07714
4	Russian Fed.	10.6	145	1537	8269	0.3942483	3.71932	14.97104
5	Japan	9.6	127	1219.2	26937	0.450126	4.68881	5.24711
6	Argentina	3.7	37	136.9	11083	1.5450270	41.75749	43.77377
7	Brazil	1.9	170	323	7752	0.3362706	17.69845	34.44271
8	China	2.7	1275	3442.5	4577	0.0448361	1.6606	3.07597
9	India	1	1009	1009	2681	0.0566561	5.66561	16.77923
10	Korea	10	47	470	17161	1.2162979	12.16298	22.25525
11	Mexico	3.9	99	386.1	8972	0.5774343	14.80601	20.20917
12	South Africa	7.8	43	335.4	10152	1.3294419	17.04413	41.11998

Notes: Column (3) reports the per capita CO_2 emission in metric tons (2000). Column (4) and column (5) report the population in 2000 in millions and the total CO_2 emission in millions metric tons (2000) respectively. Column (6) reports the per capita GDP in PPP International $ (2002). Column (7) shows a 57.16 million metric tons reduction is equal to what per capita amount emission reduction for each of the other countries. Column (8) shows a 1% reduction in emissions in the U.S. (i.e., 57.16 million metric tons) is equal to what % per capita emission reduction for each of the other countries. Column (9) shows the opportunity cost in terms of % of per capita GDP that each country would have to forego in order to reduce emissions by 57.16 million metric tons.