Energy consumption and carbon dioxide environmental efficiency for former Soviet Union economies. evidence from DEA window analysis

Arazmuradov, Annageldy

University of Bergamo

22 December 2011

Energy Consumption and Carbon Dioxide Environmental Efficiency for Former Soviet Union Economies. Evidence from DEA Window Analysis.

Annageldy Arazmuradov[*#]

[#] Department of Economics and Management of Technology, University of Bergamo, Dalmine (BG), Italy

Version: 22.12.11

Abstract

The main source of convertible energy—fossil-fuel combustion—generates desirable means for production of national output (GDP) along with an undesirable by-product—carbon dioxide (CO_2) emissions. This paper investigates the effect of this supply process for environmental quality. By introducing energy and non-energy production factors, we estimate economic and CO_2 efficiency. We build an alternative environmental efficiency indicator with respect to CO_2 emissions by applying non-parametric data-envelopment analysis (DEA)—window analysis under variable returns to scale (VRS)—to 15 former Soviet Union (FSU) economies for the period 1992–2008. There is a clear distinction between three FSU economies—Estonia, Latvia, and Lithuania (now EU member states)—and the rest of the sample in that they display better environmental performance. In these three countries, economic efficiency directly influences the environmental performance. Results also show that over time FSU economies improve their CO_2 environmental efficiency and comply with the Kyoto Protocol directives. However, this positive gain comes with costs; it seems there is a tradeoff between positive output production (GDP) and controlling for carbon emission. On average, we observe a 15.9-percent drop in producing GDP, while there is a 1.59 -percent rise in positive environmental CO_2 efficiency.

JEL classification: O13 C23

Keywords: Eurasia; carbon dioxide emissions; environmental efficiency; DEA window analysis.

[*] Corresponding author: Department of Economics and Management of Technology, Faculty of Engineering, University of Bergamo, via Marconi 5, 24044 Dalmine (BG), Italy; E-mail: annageldy.arazmuradov@unibg.it; Tel: (+39) 327 1608071.

1. Introduction

The reduction of anthropologic carbon dioxide (CO_2) emissions is one the major tasks confronting our civilization because it could lead to a global food supply shortage along with many others calamities, according to the Intergovernmental Panel on Climate Change (IPCC) .[1] As is well known, transition economies in the early stages put economic development in front of environmental performance, which is understandable. The problem is that if this process continues it could lead to irreversible results. In addition, CO_2 emissions are global; it is not feasible when some countries put enormous efforts into curbing emissions while others pollute—thus "refuting" all investments. An effective policy requires collective action. Transition economies with reckless consumption, population growth, and obsession with economic growth coupled with a lack of functioning environmental regulation drive global greenhouse gas (GHG) emissions; among them are the 15 former Soviet Union (FSU) economies.[2] All FSU economies have ratified the Kyoto Protocol (KP), which is aimed at combating global warming. In regard to CO_2emissions, which are the main agenda of the KP, FSU countries all together produce 8.68 percent of global CO_2 emissions from fuel combustion.[3] This is fairly high amount if compared with the world's four emission leaders: it is more than the emissions of India (5.78 percent), more than half those of all the European Union 27 (14.04 percent), nearly half those of the USA (18.11 percent), and nearly one-third those of China (23.33 percent).[4]

Given the above figures, the less-developed FSU transition economies are subject to difficult circumstances. The data from Fig. 1 point to co-movement between economic development and carbon emissions. Do these trends go at a decreasing rate? To what degree is economic production able to control carbon emissions? Emissions or undesirable outputs are inevitable, but manageable. Firms could reduce these negative outcomes to some degree by increasing their efficiency—e.g., utilizing a proper technology and input mix. The economic scale of production is considered an important notion since the increase of scale improves production efficiency, which ultimately reduces pollution in emission-prone industries (Hettige et al., 2000; Wheeler, 2001; Lucas et al., 2002).

There is a growing impact and a need for environmental regulation of private sector activities worldwide. Also, environmental efficiency is important and is a part of the economic policy goals of the European

---

[1] The Intergovernmental Panel on Climate Change (IPCC) was established on December 6, 1988 by the United Nations General Assembly and is primarily concerned with producing reports related to climate change, based on the UN Convention on Climate Change (UNFCCC). Carbon dioxide is one of the GHGs, along with methane, nitrous oxide, and sulphur hexafluoride. CO_2 comes from the burning of carbonaceous fuels (also known as fossil fuels) such as coal, oil, and gas. CO_2 emissions have dramatically increased since 2000, and it is considered a bulk element in the global warming problem. Emissions of CO_2 have increased due to petroleum and natural gas consumption, according to the Energy Information Association (EIA) (2011). Different countries contribute different levels of heat-trapping gases to the atmosphere such as CO_2. Please refer to the Appendix for the CO_2 emissions table.

[2] The FSU consist of Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.

[3] The Kyoto Protocol was the outcome of the implementation of UNFCCC, which deals with issues of global warming. This protocol, which was signed by 169 states (including all fifteen FSU countries) and entered into force on February 16, 2005, aims at stabilizing GHG emission levels in the atmosphere so as to prevent the hazardous effects on climate.

[4] The data are for 2008 were presented by CDIAC and prepared for the United Nations. Source: http://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions . Accessed on December 08, 2011.

countries related to Lisbon Strategy and Göterburg priorities for sustainable development. This is pertinent to three of our sample FSU economies, which are now EU member states: Estonia, Latvia. and Lithuania. The importance of identifying environmental efficiency metrics has been mentioned by many scholars. For example, Allen (1999), Thoresen (1999), and Tyteca (1996) present broad literature reviews and discussions on the need for environmental indicators that could provide warning signals calling for appropriate actions and policy decisions. Hence, it is important to assess empirically the environmental performance of these FSU economies with regard to CO_2. In this respect, we propose to combine the economic and environmental sides of economic development to shed light on the efficient use of available resources by constructing an environmental efficiency index for CO_2. We believe that carbon emissions-related indictors are better assessed by "efficiency" methods because they are mainly generated by human behavior. We do this by applying popular non-parametric data-envelopment analysis (DEA)[5] methodology.

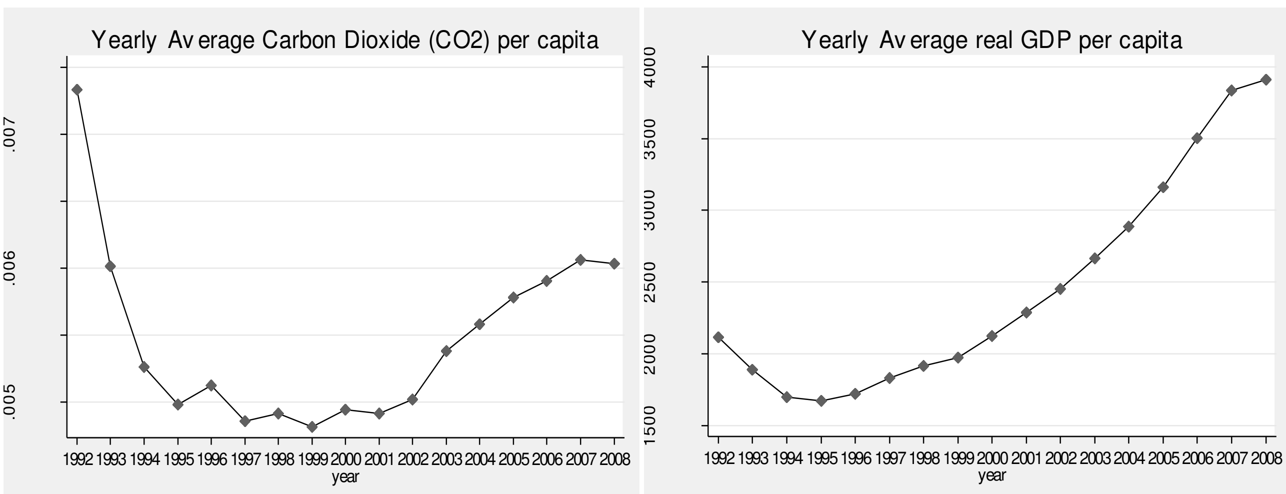

Figure 1. Carbon dioxide (CO_2) and real GDP per capita development.

Previously, many scholars used production-frontier analysis, called the DEA directional distance function approach, in building environmental efficiency measures that considered desirable and also undesirable outputs (Fare et al., 1989, 1994, 1996, 2004a, 2004b; Chung et al., 1997; Tyteca, 1997; Zaim & Taskin, 2000; Zaim, 2004).These studies considered joint production of positive and negative outputs and use direction as a policy variable that is designed to reduce inputs or increase outputs, which is a powerful technique that provides flexibility in decision making (Färe et al., 2004c). Nevertheless, Coelli et al. (1998) and Halkos and Tzemeres (2009) pointed out that it is possible to consider the negative output—CO_2 in our case—as a neutral variable that is similar to conditions of imposing strict inequality constraints on negative outputs. Haynes et al. (1993) used similar arguments in their study of pollution.

Following the aforementioned contributions, we apply variation of the traditional DEA method, called DEA window analysis (DEA-WA), which takes account of the dynamic or inter-temporal scheme of the production process to obtain a CO_2 environmental efficiency index. That said, it is suitable for panel data, as in our case: 15 countries and 17 years, 1992–2008. The advantage of DEA window analysis is that it

[5] For the popularity of the DEA approach, please refer to the study of Emrouznejad et al. (2008), in which the authors present advantages and applications of this non-parametric technique for the past 30 years. Zhou et al. (2008) display the applications of DEA to various environmental problems, and Cooper et al. (2004) overview applications of DEA for different countries.

takes account of the time dimension and simultaneously assesses the stability of efficiency evaluation across and within the chosen window (Yue, 1992; Hartman & Storbeck, 1996; Webb, 2003; Asmild et al., 2004; Cooper et al., 2007; Halkos & Tzeremes, 2008, 2009a, 2009b, 2009c, 2011). Specifically, this method was used in the study by Halkos and Tzeremes (2009a) but in assessing sulfur emissions and building an environmental efficiency index for 21 Organization for Economic Cooperation and Development (OECD) countries. In their paper, the authors use a production-function approach with capital and labor as inputs and GDP and sulphur emissions (SO_x) as outputs. In our study, for the first time (to the best of our knowledge) we propose inclusion of a third input variable, which is energy consumption, to obtain efficiency metrics. Moreover, we assess the CO_2 efficiency using transition FSU post-communist economies that were not studied before in this framework.

Table 1. A Three-Year Window of Environmental-Efficiency Ratio for Armenia[6]

Year → Window↓	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	Average
window 1	1.00	1.00	1.00															1.00
window 2		1.00	1.00	1.00														1.00
window 3			1.00	1.00	0.99													1.00
window 4				1.00	0.99	1.00												1.00
window 5					1.00	1.00	1.00											1.00
window 6						1.00	1.00	1.00										1.00
window 7							1.00	1.00	0.99									1.00
window 8								1.00	0.99	0.99								0.99
window 9									1.00	1.00	1.00							1.00
window 10										1.00	1.00	1.00						1.00
window 11											1.00	1.00	1.00					1.00
window 12												1.03	1.04	1.03				1.03
window 13													1.03	1.02	1.02			1.02
window 14														1.02	1.01	1.01		1.01
window 15															1.01	1.01	1.00	1.01
Average	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.02	1.01	1.01	1.00	1.00

In our study, we contribute to and extend existing research in the following ways. First, we focus on the previously unstudied fifteen FSU countries. Second, we employ inter-temporal DEA window analysis to estimate each country's efficiency score employing different outputs (real GDP and CO_2 emissions). This

[6] Due to the enormous number of tables, we present results only for Armenia. Results for the other 14 countries are available upon request.

is based on three main points: first, DEA window analysis takes account of the time dimension (dynamics) of each country's efficiency trend, a major concern of stochastic approaches that incorporates external shocks; second, it accommodates multiple inputs in production of desirable and undesirable outputs; and third, it allows comparison (benchmarking) of heterogeneous sample countries, which is not the case in most parametric panel-data analyses that produce single expected-value estimates for the whole sample (e.g., mean). However, it is a good complement to other panel estimation techniques, especially for decision-making purposes. For example, when access to detailed statistics is absent, DEA methodology could provide an alternative opportunity for conducting research.

Our main results are the following: (1) a huge decline in positive (GDP) efficiency of 15.9 percent is experienced by the FSU economies, (2) the FSU economies are still struggling to better control CO_2 emissions in their production processes, (3) there is a minor positive increase in environmental efficiency with regard to CO_2 on average for the period 1992–2008, and (4) it seems that domestic firms experience a trade-off during the positive output (GDP) production process.

This paper is organized as follows. Section 2, Econometric Modeling, describes the data and techniques employed. Then, Section 3 discusses the main findings, and Section 4 presents a summary and the conclusions.

2. Econometric Modeling

A priori, we assume that the FSU countries, except the EU member states, are less concerned with environmental issues than developed countries and hence are more polluting. Further, they may use more energy-consuming technologies due to delayed technological advancement and the use old transportation vehicles. We also assume that energy consumption is higher compared with developed countries that use sophisticated energy-saving equipment. The relationship between energy use from fossil-fuel combustion and carbon emissions has been extensively researched (Ang, 1999; Ang, 2007; Ozturk & Acaravci, 2010; Niu et al., 2011; Pao & Tsai, 2011; Wang et al., 2011). For example, studies report a direct causality from energy consumption to carbon dioxide emissions (Soytas et al., 2007; Apergis & Payne, 2010). Energy-efficiency enhancements could bring substantial productivity, reducing fossil-fuel burning and hence curbing CO_2 emissions along with other greenhouse gases (Barker et al., 2007; Scott et al., 2008).

The majority of FSU economies rely on agricultural and production sectors that use natural resources, chemicals, and basic metals that are considered environmentally sensitive (Lee & Roland-Holst, 1997). These industries are principal polluters due to the large volume of production, GHG emissions, and production of hazardous chemical by-products. Another point is that the governments of most of the FSU economies heavily subsidize these industries, which often results in increased pollution due to sizable inefficiencies in the use of resources. Reduction of these subsidies could decrease the scale of production and improve environmental performance (Lucas et al., 1992; Birdsall & Wheeler, 1993; Dasgupta et al., 1997).

The literature strands on environmental pollution and economic policies discuss various policy responses that are very pertinent to the FSU economies. Some scholars propose elimination of energy subsidies, which could increase energy efficiency by shifting industry away from energy-intensive sectors and thus reducing demand for pollution-intensive power (Vukina et al., 1999). Other researchers argue that higher energy prices also induce shifts from capital- and energy-intensive production techniques to labor- and materials-intensive techniques, which are often more pollution-intensive in other ways (Mani et al., 2000). The extent and potential effects of this production technology shift in environmental quality related to carbon emissions is the scope of this study. Hence, we focus our attention on the production process side since it gives us an opportunity to analyze countries' production efficiency (or efforts) by combining multiple inputs and outputs. We aim to construct the CO_2 environmental-efficiency ratio by first obtaining an efficiency score for each country from production of "good" output (GDP), separately from undesirable, or "bad" output (CO_2), using the same inputs: labor, capital, and energy consumption.

2.1 Data and Measurements

We used an updated online United Nations Conference on Trade and Development (UNCTAD) database (2011) for our variables. The *input variables* are labor (L), which is measured as total workers; capital (K), which is the gross capital formation of the economy; and total energy consumption (E). The *output variables* are undesirable (CO_2), which is measured in metric tons, and desirable (GDP), which is gross domestic product. The energy consumption and CO_2 emissions variables were taken from the U.S. Energy Information Administration (EIA), and all monetary variables are in real terms. Our sample consists of 15 former Soviet Union economies, three of which (Estonia, Latvia, and Lithuania) are European Union member states. This composition of the sample helps us to build a global production frontier and compare countries on their efficiency performance. The data description and sources are given in the Appendix.

2.2 Production Function: Inputs and Outputs

We assume that firms in the FSU economies are under the same environmental constraint, due to CO_2 being considered a global polluter that is regulated by tradable pollution tax among KP countries. In building the production function, we include energy consumption (E) along with labor (L) and capital (K) as input factors. Since we are aiming to assess negative output (CO_2) and are basing our analysis on the previous contributions mentioned, we believe that energy consumption is the main factor driving CO_2 emissions and thus should be included in the production function in efficiency estimation. Hence, the production function in our study follows the following formulation for desirable (Y^{GDP}) and undesirable (Y^{CO2}) outputs:

$$Y^{GDP} = f(K, L, E) \tag{1}$$

$$Y^{CO2} = f(K, L, E) \ , \tag{1.a}$$

where we use the same input factors but different outputs, one for good (GDP) and one for bad output (CO_2). K (capital), L (labor), and E (energy consumption) are the input production factors.

Assuming weak substitutability of inputs, DEA-WA is favorable for our purpose because (1) we could rank countries according to their efficiency; and (2) it serves for decision making—e.g., to assess best performers. Furthermore, DEA-WA allows us to accommodate heterogeneity across countries without regard to collecting information on input and output prices, technological production schemes, market structure, etc. Another feature of DEA-WA is that it accommodates variables with different measurement units. It also exempts us from specifying the precise form of the production function.

Table 2a. Good (GDP) Efficiency.

Country/year	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	Average
Armenia	1.00	1.00	1.00	1.00	0.99	0.99	0.99	1.00	1.00	0.98	0.98	0.95	0.96	0.92	0.86	0.83	0.81	0.96
Azerbaijan	1.00	0.47	0.58	0.52	0.49	0.45	0.48	0.56	0.72	0.76	0.52	0.41	0.40	0.52	0.68	0.94	1.00	0.62
Belarus	0.42	0.44	0.44	0.51	0.54	0.57	0.61	0.72	0.73	0.81	0.88	0.79	0.75	0.74	0.65	0.62	0.60	0.64
Estonia	0.99	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Georgia	0.50	1.00	0.96	0.92	0.92	0.97	0.81	0.87	0.89	0.94	0.87	0.97	0.98	0.91	1.00	0.92	1.00	0.91
Kazakhstan	0.56	0.71	0.56	0.68	0.87	0.79	0.74	0.69	0.74	0.71	0.73	0.81	0.79	0.71	0.66	0.71	0.78	0.72
Kyrgyzstan	0.69	0.80	0.92	0.87	0.84	0.84	0.98	0.87	0.82	0.89	0.97	1.00	0.97	0.97	0.90	0.93	1.00	0.90
Latvia	1.00	1.00	0.98	0.98	1.00	0.99	0.99	0.97	1.00	1.00	1.00	1.00	0.96	1.00	1.00	0.99	1.00	0.99
Lithuania	0.96	1.00	1.00	1.00	0.99	1.00	0.97	1.00	1.00	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99
Moldova	0.55	0.70	0.87	0.97	0.91	0.89	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.99	0.93
Russia	1.00	1.00	1.00	1.00	0.99	1.00	0.98	1.00	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tajikistan	0.59	0.62	0.70	0.81	1.00	1.00	1.00	0.97	1.00	0.95	0.98	0.96	0.98	0.99	0.99	0.91	1.00	0.91
Turkmenistan	0.58	0.63	0.59	0.58	0.58	0.58	0.62	0.56	0.62	0.67	0.73	0.75	1.00	1.00	1.00	1.00	0.97	0.73
Ukraine	0.63	0.61	0.60	0.90	0.89	0.73	0.58	0.66	0.67	0.74	0.88	0.78	0.84	0.79	0.75	0.67	0.68	0.73
Uzbekistan	0.21	0.44	0.43	0.43	0.51	0.63	0.54	0.63	0.63	0.71	0.66	0.56	0.42	0.44	0.48	0.47	0.51	0.51
Average	**0.71**	**0.76**	**0.78**	**0.81**	**0.83**	**0.83**	**0.81**	**0.83**	**0.85**	**0.88**	**0.88**	**0.87**	**0.87**	**0.87**	**0.86**	**0.87**	**0.89**	**0.84**

2.3 DEA window analysis method and Environmental Efficiency Index

The DEA window analysis is either time dependent or a dynamic type of DEA. The method was initially introduced by Klopp (1985) in studies of U.S. Army recruitment (Cooper et.al., 2007, p. 321).

We adopt the formulation as in Asmild et al. (2004), Halkos and Tzeremes (2009a, 2011) as follows. Let us assume that the *N* decision-making units (DMUs), with countries in our case (n = 1,..., *N*), are under T period of time (t = 1,…,*T*), using **z** inputs and producing **q** outputs. Then we have panel data in which a $DMU_{n,t}$—e.g., a country n in period t—will have an s dimensional input vector of $\boldsymbol{z}_t^n = (z_{1t}^n, z_{2t}^n, \dots, z_{st}^n)'$ and a p dimensional output vector of $\boldsymbol{q}_t^n = \left(q_{1t}^n, q_{2t}^n, \dots, q_{pt}^n\right)'$.

Further, the window j_w with j* w observations will be with width w, 1 ≤ w ≤ T-j, and start at time j, 1 ≤ j ≤ T. Then the matrix of inputs (1) and outputs (2) will be the following:

$$\boldsymbol{Z}_{jw} = (z_j^1, z_j^2, \dots, z_j^N, z_{j+1}^1, z_{j+1}^2, \dots, z_{j+1}^N, \dots, z_{j+w}^1, z_{j+w}^2, \dots, z_{j+w}^N) \tag{2}$$

$$\boldsymbol{Q}_{jw} = (q_j^1, q_j^2, \dots, q_j^N, q_{j+1}^1, q_{j+1}^2, \dots, q_{j+1}^N, \dots, q_{j+w}^1, q_{j+w}^2, \dots, q_{j+w}^N)\ . \tag{2.a}$$

The window analysis problem that needs to be solved is as follows:

$$\theta'_{jw,t} = \min_{\theta,\gamma} \theta$$

$$\text{s.t.} -\boldsymbol{Z}_{jw}\gamma + \theta z'_t \geq 0 \tag{3}$$

$$\boldsymbol{Q}_{jw}\gamma - q'_t \geq 0$$

$$\gamma_n \geq 0 \ (n = 1, \dots, N * w).$$

We insert a variable returns to scale (VRS) restriction in our estimation for formula (3) that allows for VRS across sample $\sum_1^N \gamma_n = 1$ (Banker et al., 1984). This is important because our sample countries are heterogeneous with different production mixes and corresponding levels of economic regulation and laws in regard to domestic firms. As noted, we use an input-oriented (or input-saving) approach that consists of minimizing inputs while keeping a given output level. This is feasible when a decision maker (e.g., a firm) can control its inputs, which are in our case are labor, capital, and energy consumption. Since we deal with undesirable output (CO_2), we want increased inputs for a given level of negative output. For example, 100 tons of CO_2 output produced by 1,000 units of labor (workers) and 1,000 units of capital is "socially" better than the same output produced by 100 workers and 100 units of capital. However, the opposite logic applies for positive (GDP) output.

Table 3. DEA Window Analysis Numerical Illustration

Definition	Formula	Solution
# of windows	W = K-P+1	15 = 17-3+1
# of "different" DMUs	N*P*W	15*3*15 = 675
Δ # of DMUs	N(P-1)(K-P)	15(3-1)(17-3) = 420
Our sample (DMUs)	K*W	17*15 = 255

Note: DMUs relates to decision-making units: countries in our case. W-number of windows (15); K-number of periods (17 years); P-length of window (3 years), and N-number of countries (15 DMUs). *Source*: Cooper et al. (2007).

We obtain separate efficiency scores according to Eqs. 1 and 1.a with the help of the DEA window-analysis technique.[7] Then we construct the CO_2 environmental-efficiency (ω^{CO2}) index for each FSU country according to following equation:

[7] The DEA window-analysis model was run with the help of DEA-Solver software developed by Kaoru Tone (Cooper et al., 2007).

$$\omega^{CO2} = \frac{Good\ Efficiency}{Bad\ Efficieny} = \frac{\theta^{GDP}}{\theta^{CO_2}}\ . \qquad (4)$$

Table 1 demonstrates the principle of window analysis for Armenia. As can be seen, we have 15 windows, calculated by using the formula in row 1 of Table 3. The DEA window principle is dynamic since it is based on the principle of moving averages. In addition, each country is benchmarked with itself in current and preceding years, and also with other countries. By this method, we gain 420 more observations (from an original 255) in obtaining efficiency scores (675 – 255 = 420), as explained in Table 3, third row. This is especially favorable to our small sample of 15 countries and asymptotic properties.

3. Empirical Findings

Environmental efficiency's dynamic development under the DEA-WA method is illustrated in Table 1. A three-year window (w = 3) and 15 countries gives us 45 observations for Armenia. So the first window is the years 1992, 1993, and 1994, and in each year the country is treated as a different observation. The second window drops the initial year (1993, 1994, and 1995), and this continues until 2008. This table could be interpreted in two ways: the "column view" that gives the stability of the environmental-efficiency score for Armenia across different data sets that is generated by the replacement procedure, and the "row view," which shows the inter-temporal development or trend. From the table, we could say that Armenia's performance was better in the years 2000–2008 vs. 1992–2000 by observing the higher average scores (bottom row). The higher the score, the better is the environmental performance of the country.

Tables 2a–2c guide us through building the environmental index according to Eq. 4 and its components. Table 2a provides good (GDP) efficiency scores for all countries. Here, the efficiency scores are bound and range from 0 to 1 (100 percent), with 1 being fully efficient. In our case, since we used an input-oriented model, it means being able to minimize inputs to produce a given country's desirable (or positive) output (GDP). Hence, the higher the score, the better is the country in this production process. The best performers on a yearly average for the period 1992–2008 are the EU member states—Estonia (100 percent), Latvia (99 percent), and Lithuania (99 percent)—and also Russia (100 percent). The laggards are Uzbekistan (51 percent) and Azerbaijan (62 percent). This means there are 49 percent and 38 percent "inefficiencies," respectively.

Bad or negative output (CO_2) efficiency scores are presented in Table 2b. Here, the scores are also bound in a 0–1 scale, but they have a different meaning from the positive (GDP) ones. From the efficiency point of view, we aim to reduce pollution per unit of inputs used, spreading the observed level of pollution to more utilized inputs in production. The lower the score, the better is the performance in regard to carbon reduction.[8] Put simply, if you are unable to minimize the inputs in producing for a given level of CO_2, then

[8] To further explain "negative efficiency" scores, we strive to obtain lower values of bad (CO_2) efficiency because only in that case would it be "positive." The lower the value, the better an economy is controlling CO_2 emissions. In other words, given high efficiency scores, the country is "inefficient" in reducing input factors for a given level of CO_2 emissions because it would be ideal if it produced a given level of carbon emissions with more production factors (capital, labor, and energy consumption). Maybe an example could clarify this further. Assume that country *A* produces 1 ton of CO_2 with one unit each of capital, labor,

it is favorable. If, in contrast, the country is good—e.g., has a higher efficiency score—then it produces carbon emissions with lower levels of labor, capital, and energy use. On a yearly average for the period studied, we obtained: Latvia (58 percent), Belarus (76 percent), Georgia (83 percent), and Azerbaijan (88 percent). Hence, Latvia, for example, is the leader, having 42 percent (100 percent – 58 percent) of "good efficiency" we may call it. Still, sample total yearly average is a warning due to the fact that countries are unable to better curb their carbon emissions, which is shown by (90 percent)—e.g., only 10 percent of positive efficiency.

Table 2b. Bad (CO_2) Efficiency.

Country/year	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	Average
Armenia	1.00	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.98	0.98	0.95	0.93	0.90	0.85	0.83	0.81	0.95
Azerbaijan	1.00	0.95	0.97	0.98	0.92	0.85	1.00	1.00	1.00	0.83	0.78	0.74	0.73	0.76	0.80	0.82	0.84	0.88
Belarus	0.74	0.81	0.78	0.82	0.78	0.75	0.72	0.74	0.73	0.73	0.76	0.76	0.75	0.76	0.76	0.75	0.73	0.76
Estonia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Georgia	0.62	1.00	0.87	0.89	0.86	0.80	0.75	0.76	0.79	0.85	0.77	0.88	0.90	0.84	0.94	0.81	0.79	0.83
Kazakhstan	1.00	1.00	0.94	0.97	1.00	0.96	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
Kyrgyzstan	0.71	0.85	0.93	0.87	0.85	0.87	1.00	0.90	0.82	0.86	0.95	1.00	0.97	0.96	0.90	0.92	1.00	0.90
Latvia	0.61	0.60	0.69	0.62	0.54	0.55	0.53	0.57	0.58	0.56	0.55	0.53	0.55	0.57	0.60	0.58	0.58	0.58
Lithuania	0.76	0.92	0.94	0.90	0.93	0.98	0.97	1.00	0.99	0.97	1.00	0.99	0.96	0.95	0.96	0.95	1.00	0.95
Moldova	0.82	0.88	1.00	1.00	0.98	0.97	0.97	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.00	0.99	0.98
Russia	1.00	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.98	0.99	1.00	1.00	1.00	1.00	0.96	0.99	0.99
Tajikistan	0.59	0.62	0.70	0.81	1.00	1.00	1.00	0.98	1.00	0.95	0.96	0.95	0.98	0.99	0.98	0.92	1.00	0.91
Turkmenistan	0.74	0.81	0.73	0.72	0.71	0.74	0.75	0.72	0.80	0.91	0.96	0.96	1.00	1.00	1.00	1.00	1.00	0.86
Ukraine	0.95	0.95	0.95	1.00	1.00	0.97	0.97	1.00	0.97	0.96	0.99	1.00	0.98	0.98	0.98	0.96	0.96	0.97
Uzbekistan	0.78	1.00	0.95	0.98	0.98	1.00	0.97	1.00	0.99	0.99	1.00	0.99	0.99	0.97	1.00	1.00	0.98	0.98
Average	**0.82**	**0.89**	**0.90**	**0.90**	**0.90**	**0.89**	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**	**0.92**	**0.92**	**0.91**	**0.92**	**0.90**	**0.91**	**0.90**

Table 2c depicts the main results of this study: CO_2 environmental-efficiency scores. The meaning of this index is that it is a ratio: the lower the denominator (CO_2 efficiency, Eq. 4), the higher the score. In other words, the better countries are in reducing carbon emissions during the production process of positive output (GDP), the higher are the scores. Again, the EU member states Estonia, Latvia, and Lithuania

and energy. Also assume that country *B* produces the same amount of negative output (CO_2) with 4 units each of the factor inputs. Which country is better? The answer is B due to more input factors producing the same amount of pollution.

demonstrate good performance. However, some other countries of the old Soviet Block—Armenia, Georgia, Russia, and Tajikistan—also display good results. In our estimation, we could obtain relatively low carbon environmental-efficiency indexes compared with other closely related emission-related studies. Since there is no study with which to compare our obtained estimates, we could only compare them with a similar index measure for sulfur emissions. As an example, Halkos and Tzeremes (2009a) report an environmental-efficiency ratio obtained by DEA-WA for SO_2 ranging from min 0.81 for Canada and max 32.47 for Denmark. In our study, the range is from 0.52 (Uzbekistan) to 1.73 (Latvia).

Table 2c. Environmental-Efficiency Ratio (Good/Bad Efficiency)

Country/year	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	Average
Armenia	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.02	1.01	1.01	1.00	1.00
Azerbaijan	1.00	0.49	0.61	0.53	0.53	0.53	0.48	0.56	0.72	0.92	0.66	0.55	0.54	0.68	0.85	1.15	1.18	0.71
Belarus	0.56	0.55	0.57	0.62	0.69	0.76	0.85	0.98	0.99	1.10	1.16	1.04	1.00	0.97	0.85	0.83	0.82	0.84
Estonia	0.99	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Georgia	0.82	1.00	1.10	1.04	1.08	1.22	1.08	1.14	1.14	1.11	1.14	1.10	1.09	1.09	1.06	1.13	1.26	1.09
Kazakhstan	0.56	0.71	0.60	0.70	0.87	0.83	0.77	0.69	0.74	0.71	0.73	0.81	0.79	0.71	0.66	0.71	0.78	0.73
Kyrgyzstan	0.97	0.94	0.99	1.00	0.98	0.96	0.98	0.97	0.99	1.03	1.02	1.00	1.01	1.01	1.00	1.01	1.00	0.99
Latvia	1.63	1.66	1.42	1.59	1.85	1.79	1.85	1.71	1.73	1.79	1.82	1.89	1.75	1.74	1.66	1.71	1.72	1.73
Lithuania	1.26	1.09	1.07	1.12	1.07	1.02	1.01	1.00	1.01	1.02	1.00	1.01	1.04	1.05	1.03	1.06	1.00	1.05
Moldova	0.68	0.79	0.87	0.97	0.92	0.92	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95
Russia	1.00	1.00	1.00	1.00	0.99	1.01	0.99	1.00	1.00	0.99	1.01	1.00	1.00	1.00	1.00	1.04	1.01	1.00
Tajikistan	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.03	1.01	1.00	1.01	1.01	0.99	1.00	1.00
Turkmenistan	0.79	0.79	0.81	0.80	0.81	0.79	0.82	0.79	0.78	0.73	0.76	0.78	1.00	1.00	1.00	1.00	0.97	0.85
Ukraine	0.66	0.64	0.63	0.90	0.89	0.75	0.60	0.66	0.69	0.78	0.89	0.78	0.86	0.80	0.77	0.70	0.71	0.75
Uzbekistan	0.26	0.44	0.45	0.44	0.52	0.63	0.56	0.63	0.64	0.72	0.66	0.57	0.42	0.45	0.48	0.47	0.52	0.52
Average	**0.88**	**0.87**	**0.87**	**0.91**	**0.95**	**0.95**	**0.93**	**0.94**	**0.96**	**0.99**	**0.99**	**0.97**	**0.97**	**0.97**	**0.96**	**0.99**	**1.00**	**0.95**

Table 4 gives us a condensed view to compare obtained measures from DEA-WA, where we can observe the strong decline in productive efficiency for positive national output (GDP)—a yearly average decline of 16 percent. On the other hand, on average carbon-controlling efficiency rose during the sample period by around 1 percent annually. The lower the CO_2 efficiency the better, but we obtained 0.90 (or 90 percent), which is a very high and negative result for purposes of controlling carbon emissions. With regard to environmental efficiency (ω^{CO2}), as mentioned before a higher value is better. The best performers are

Latvia (1.73) and Georgia (1.09), followed by Armenia, Tajikistan, Russia, and Estonia, which all have (1.00).

The striking fact is the dramatic reduction in positive (GDP) efficiency of non-EU post-communist economies. On average, we observe a drastic drop in national output production efficiency for the whole period 1992–2008: Uzbekistan (-47 percent), Azerbaijan (-41 percent), Belarus (-35 percent), Ukraine (-26 percent), and Turkmenistan (-26 percent). In contrast, EU member states have only a slight decline: Estonia (-0.12 percent), Latvia (-0.92 percent) and Lithuania (-0.39 percent). The positive message is that on average FSU economies are learning to deal with carbon emissions (columns 3–4 in Table 4)—for example, Tajikistan (3.58 percent), Georgia (2.79 percent), Kyrgyzstan (2.42 percent), and Turkmenistan (2.04 percent)—and improve their carbon-related efficiency.

Table 4. Average Environmental-Efficiency Ratios (1992–2008).

	Good (GDP)Efficiency		**Bad (CO_2) Efficiency**		**Environmental-Efficiency Ratio (GDP Efficiency/CO_2 Efficiency)**	
	Average Overall Efficiency scores (1992-2008)	Average Annual Growth (1992-2008, % change)	Average Overall Efficiency scores (1992-2008)	Average Annual Growth (1992-2008, % change)	Average Overall Efficiency Scores (1992-2008)	Average Annual Growth (1992-2008, % change)
Armenia	0.96	-4.58%	0.95	-1.27%	1.00	0.00%
Azerbaijan	0.62	-40.59%	0.88	-0.79%	0.71	4.10%
Belarus	0.64	-34.87%	0.76	0.01%	0.84	2.73%
Estonia	1.00	-0.12%	1.00	0.00%	1.00	0.08%
Georgia	0.91	-6.58%	0.83	2.79%	1.09	3.05%
Kazakhstan	0.72	-26.92%	0.99	0.03%	0.73	2.80%
Kyrgyz Republic	0.90	-9.05%	0.90	2.42%	0.99	0.24%
Latvia	0.99	-0.92%	0.58	-0.13%	1.73	0.60%
Lithuania	0.99	-0.39%	0.95	1.91%	1.05	-1.36%
Moldova	0.93	-4.82%	0.98	1.24%	0.95	2.62%
Russia	1.00	-0.41%	0.99	-0.05%	1.00	0.08%
Tajikistan	0.91	-7.04%	0.91	3.58%	1.00	0.01%
Turkmenistan	0.73	-25.73%	0.86	2.04%	0.85	1.57%
Ukraine	0.73	-26.45%	0.97	0.09%	0.75	1.35%
Uzbekistan	0.51	-46.98%	0.98	1.65%	0.52	5.94%
Average	**0.84**	**-15.70%**	**0.90**	**0.90%**	**0.95**	**1.59%**

From Fig. 2, we observe the positive rising trend of environmental improvement, which is a yearly average of 1.59 percent increase. This observation points out effective domestic policies for raising the efficiency of firms that lead to curbing carbon emissions. This also could be due to globalization—e.g., FSU economies are heavily involved in international trade, purchasing already-advanced technology from developed countries that possibly improves input mix in the production process. It is hard to believe that this positive climb of the environmental index is due to strong enforcement of domestic environmental regulation. However, the threat of potential “huge” expenses due to the Kyoto Protocol agreement may have stimulated the transition of low-income FSU economies.

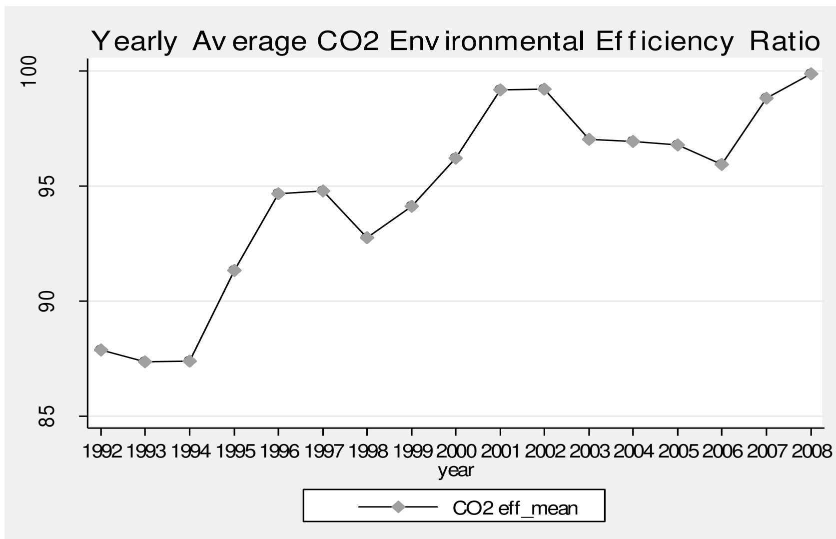

Fig 2. Average CO_2 environmental-efficiency index for 15 FSU economies for 1992–2008.

4. Conclusion

This paper investigates carbon dioxide environmental-efficiency performance of 15 former Soviet Union economies by applying a non-parametric data-envelopment analysis (DEA)–window analysis framework for the period 1992–2008.

In general, FSU economies have improved their environmental efficiency with regard to the main greenhouse pollutant (CO_2) by 1.59 percent per year during 1992–2008. This finding supports the aims of the Kyoto Protocol on arresting pollutant greenhouse emissions. However, it seems that this positive gain comes at a very high cost, as we observe the dramatic decline in positive output (GDP) production efficiency. It seems that there is a tradeoff and that firms sacrifice output level for reducing carbon emissions.

This study shows that it is not an economic development per se; it is more an economic structure, especially the production mix (combination of inputs), matters involved in curbing carbon emissions, and correspondingly the enhancement of environmental efficiency. We saw that CO_2 emissions are rising in the

FSU economies but that the ability (or efficiency) in curbing them is also rising, as our results demonstrate. Hence, it would be more feasible to assess countries on efficiency grounds. Countries that are members of EU such as Estonia, Latvia, and Lithuania are corroborating this finding even though their economic growth is miserable.

To effectively control carbon emissions and other related pollutants, FSU economies should pay attention to creating sound environmental regulations that can provide incentives for domestic firms to comply with emission restrictions today in order to plant eco-culture seeds that could bring fruits for future generations. This is very important due to emission-related ecological problems that arrive with a 50–100- year lag.

We believe that external channels such as international trade, foreign direct investment (FDI), and foreign aid could bring a positive effect in introducing environmentally friendly production and collaborations—and in some cases even imposing them. This requires further research in these lines due to the increase of FDI and foreign-aid allocations in FSU economies.

Acknowledgements

References

Allen, K. (1999). DEA in the ecological context: An overview. In: G. Westermann (Ed.), *Data envelopment analysis in the service sector* (pp. 203-235) Wissenschaft, Germany: Gabler Edition.

Ang W. B. (1999). Is the energy intensity a less useful indicator than the carbon factor in the study of climate change? *Energy Policy, 27*, 943–946.

Ang, J. B. (2007). CO_2 emissions, energy consumption, and output in France. *Energy Policy, 35*, 4772–4778.

Apergis , N., & Payne, J. E. (2010). The emissions, energy consumption, and growth nexus: Evidence from the commonwealth of independent states. *Energy Policy, 38*, 650–655.

Asmild, M., Paradi, C. V., Aggarwall, V., & Schaffnit, C. (2004). Combining DEA window analysis with the Malmquist Index approach in a study of the Canadian banking industry. *Journal of Productivity Analysis, 21*, 67–89.

Banker, R. D., Charnes, A., Cooper, W. W. (1984). Models for estimation of technical and scale inefficiencies in data envelopment analysis. *Management Science, 30*, 1078–1092.

Barker, T., Ekins, P., & Foxon, T. (2007). Macroeconomic effects of efficiency policies for energy-intensive industries: The case of the UK Climate Change Agreements, 2000–2010. *Energy Economics, 29*, 760–778.

Birdsall, N., & Wheeler, D. (1993). Trade policy and industrial pollution in Latin America:

Where are the pollution havens? *Journal of Environment and Development*, *Winter*(2:1), 137–49.

Coelli, T., Rao, D. S. P., & Battese, G. E. (1998). *An introduction to efficiency and productivity analysis*. Boston: Kluwer Academic Publishers.

Cooper, W. W., Seiford, L. M., & Tone, K. (2007). *Data envelopment analysis: A comprehensive text with models, applications, references and DEA-solver software* (2nd ed.). New York: Springer Science + Business Media.

Cooper, W. W., Seiford, L. M.,Thanassoulis, E., & Zanakis, S. H. (2004). DEA and its uses in different countries. *European Journal of Operational Research, 154*, 337–344.

Chung, Y. H., Färe, R., Grosskopf, S. (1997). Productivity and undesirable outputs: A directional distance function. *Journal of Environmental Management* 51, 229–240.

Dasgupta, S., Wang, H., & Wheeler, D. (1997). Surviving success: Policy reform and the future of industrial pollution in China. *World Bank Policy Research Department Working Paper No. 1856*, October.

Emrouznejad, A., Parker, B. R., & Tavares, G. (2008). Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA. *Socio-Economic Planning Sciences, 42*, 151–157.

Färe, R., & Grosskopf, S., 2004a. Modeling undesirable factors in efficiency evaluation: Comment. *European Journal of Operational Research, 157*, 242–245.

Färe, R., Grosskopf, S., & Hernandez-Sancho, F. (2004b). Environmental performance: An index number approach. *Resource and Energy Economics, 26*, 343–352.

Färe, R., Grosskopf, S., & Whittaker, G. (2004c). Distance functions with applications to DEA. In: W. W. Cooper, L. M. Seiford, & J. Zhu (Eds.), *Handbook on data envelopment analysis* (pp. 139–152). Place of publication: Kluwer Academic Publishers.

Färe, R., Grosskopf, S., & Lovell, C. A. K. (1994). *Production frontiers*. Cambridge, UK: Cambridge University Press.

Färe, R., Grosskopf, S., Lovell, C. A. K., & Pasurka, C. (1989). Multilateral productivity comparisons when some outputs are undesirable: A nonparametric approach. *The Review of Economics and Statistics*, *71*, 90–98.

Färe, R., Grosskopf, S., & Tyteca, D. (1996). An activity analysis model of the environmental performance of firms—application to fossil-fuel-fired electric utilities. *Ecological Economics, 18*, 161–175.

Halkos, G., & Tzeremes, N. G. (2008). Trade efficiency and economic development: Evidence from a cross country comparison. *Applied Economics*, *40*, 2749–2764.

Halkos, G., & Tzeremes, N. G. (2009a). Exploring the existence of Kuznets' curve in countries' environmental efficiency using DEA window analysis. *Ecological Economics*, *68*, 2168–2176.

Halkos, G., & Tzeremes, N. G. , (2009b). Electricity generation and economic efficiency: Panel data evidence from world and east Asian countries. *Global Economic Review, 38*, 251‒263.

Halkos, G., & Tzeremes, N. G. (2009c). Economic efficiency and growth in the EU enlargement. *Journal of Policy Modeling, 31*, 847–862.

Halkos, G., & Tzeremes, N. G. (2011). Oil consumption and economic efficiency: A comparative analysis of advanced, developing and emerging economies. *Ecological Economics, 70*, 1354–1362.

Haynes, S .K. E., Ratick, S., Bowe, S., & Cummings-Saxton, J. (1993). Environmental decision models: U.S. experience and a new approach to pollution management. *Environmental International, 19*, 261–275.

Hartman, T. E., & Storbeck, J. E. (1996). Input congestion in loan operations. *International Journal of Production Economics, 46*(47), 413‒421.

Hettige, M., Dasgupta, S., & Wheeler, D**.** (2000). What improves environmental compliance? Evidence from Mexican industry. *Journal of Environmental Economics and Management*, *39*1, 39–66.

Klopp, G. A., (1985), The analysis of the efficiency of productive systems with multiple inputs and outputs, Ph.D. dissertation, University of Illinois, Chicago.

Lee, H., & Roland-Holst, D. (1997). The environment and welfare implications of trade and tax policy. *Journal of Development Economics, February*, (52), 65–82.

Lucas, R., Hettige, H. & Wheeler, D. (1992). The toxic intensity of industrial production: Global patterns, trends, and trade policy. *American Economic Review Papers and Proceedings*, *(May, 82)*2, 478–81.

Lucas, R., Dasgupta, S., & Wheeler, D. (2002). Plant size, industrial air pollution, and local incomes: Evidence from Mexico and Brazil. *Environment and Development Economics, 7*, 365–381.

Mani, M., Hettige, H., & Wheeler, D**.** (2000). Industrial pollution in economic development: The environmental Kuznets curve revisited. *Journal of Development Economics, 2*(2), 445–76.

Niu, S., Y., Ding, Y., Niu, Y., Li, & G., Luo. 2011. Economic growth, energy conservation and emissions reduction: A comparative analysis based on panel data for 8 Asian-Pacific countries. *Energy Policy* 39: 2121–2131.

Ozturk, I., & Acaravci, A. (2010). CO_2 emissions, energy consumption and economic growth in Turkey. *Renewable and Sustainable Energy Reviews, 14*, 3220–3225.

Pao, H. T., & Tsai, C. M. Modeling and forecasting the CO_2 emissions, energy consumption, and economic growth in Brazil. *Energy, 36*, 2450–2458.

Scott, M. J., Roop, J. M., Schultz, D. M., Anderson, & Cort, K. A. (2008). The impact of DOE building technology energy efficiency programs on U.S. employment, income and investment. *Energy Economics*, *30*(2), 2283–2301.

Soytas, U., Sari, R., & Ewing, B. T. (2007). Energy consumption, income, and carbon emissions in the United States. *Ecological Economics, 62*, 482–489.

Thoresen, J. (1999). Environmental performance evaluation– a tool for industrial improvement. *Journal of Cleaner Production, 7*, 365–370.

Tyteca, D. (1996). On the measurement of the environmental performance of firms–a literature review and a productive efficiency perspective. *Journal of Environmental Management, 46*, 281–308.

Tyteca, D. (1997). Linear programming models for the measurement of environmental performance of firms—concepts and empirical results. *Journal of Productivity Analysis, 8*, 183–197.

Vukina, T., Beghin, J. C., & Solakoglu, E. G. (1999). Transition to markets and the environment: Effects of the change in the composition of manufacturing output. *Environment and Development Economics, 4*(4), 582–98.

Wang, S. S., Zhou, D. Q., Zhou, P., & Wang, Q. W. (2011). CO_2 emissions, energy consumption and economic growth in China: A panel data analysis. *Energy Policy, 39*, 4870–4875.

Webb, R. M. (2003). Levels of efficiency in UK retail banks: A DEA window analysis. *International Journal of the Economics of Business, 10* (3), 305–322.

Wheeler, D., 2001. Racing to bottom? Foreign investment and air pollution in developing countries. *Journal of Environment & Development*, *10*(3), 225–245.

Yue, P. 1992. Data envelopment analysis and commercial bank performance: A primer with applications to Missouri banks. *Federal Reserve Bank of St. Louis Review, 74* (1), 31–45.

Zaim, O., 2004. Measuring environmental performance of state manufacturing through changes in pollution intensities: A DEA framework. *Ecological Economics, 48*, 37–47.

Zaim, O., Taskin, F., 2000. Environmental efficiency in carbon dioxide emissions in the OECD: A non-parametric approach. *Journal of Environmental Management, 58*, 95–107.

Zhou, P., Ang, B. W., & Poh, K. L. (2008). A survey of data envelopment analysis in energy and environmental studies. *European Journal of Operational Research, 189*, 1–18.

Appendix

Table. Data Description.

Variable	Symbol	Input(I) Output(O)	Units	Description	Source
GDP	GDP	O	Millions of USD	Real gross domestic product. Desirable output	UNCTAD
CO_2	CO2	O	Metric tons	Carbon dioxide emissions from fossil-fuel combustion. Undesirable output.	US EIA
Labor	L	I	Thousands of workers,	Total employed population.	UNCATD
Capital	K	I	Millions of USD	Total capital stock. Gross Capital Formation	UNCTAD
Energy Consumption	E	I	British Thermal Units (Btus)	Total Energy Consumption	US EIA

Table. Data Summary.

Variable	Obs	Mean	Std. Dev.	Min	Max
Labor	255	9.219619	18.10378	.642835	76.07874
Capital	255	14008.7	40133.15	-63.54886	306377.3
Energy Con.	255	2.877288	7.086848	.10728	34.11568
GDP	255	58621.84	162759.1	1211.461	939581.3
CO_2	255	165.8714	404.8731	3.5972	2020.194