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Hold Your Breath: A New Index of Air Quality

Andreas Buehn and Mohammad Reza Farzanegan*

Abstract

Environmental quality and climate change have long attracted attention in policy debates. Recently, air quality has emerged on the policy agenda. We calculate a new index of air quality using CO_2 and SO_2 emissions per capita as indicators and provide a ranking for 122 countries from 1985 to 2005. The empirical analysis supports the EKC hypothesis and shows a significant influence of determinants such as energy efficiency, industrial production, electricity produced from coal sources, and urbanization on air quality. According to our index, Luxemburg, Norway, Iceland, Switzerland, and Japan are among the top 5 countries in terms of air quality performance. The Democratic Republic of Congo, Eritrea, Ethiopia, Togo, and Nepal performed worst in 2005.

JEL: Q56, Q58

Keywords: Air quality, MIMIC model, EKC hypothesis, Development, Emissions

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1. Introduction

Global warming and climate change have been on the political agenda for some time. Recently, air quality has become a hot topic extensively discussed, for instance, in US politics. As of October 11, 2011, 36 entities such as states, cities, and companies petitioned the United States Court of Appeals to review or stop the implementation of the Cross-State Air Pollution Rule, which requires power plants to reduce emissions that contribute to ozone or fine-particle pollutions in other states. Worldwide, alarming figures are being frequently reported: More than 2 million premature deaths annually due to air pollution[1], let alone about 30,000 in the US. Moreover, air pollution imposes a heavy burden on government's health care budgets and households not only in the US. China – the largest producer of SO_2 emission in the world – faces health care costs due to air pollution as high as 3.8% of GDP (World Bank [2007]); implementing the Cross-State Air Pollution Rule in the US would yield \$120 and \$240 billion in health and environmental benefits. Apart from its local consequences, air pollution has a global dimension. CO_2 is the main cause of global warming, which will sooner than later aggravate food shortages, hunger and the alteration of water resources and damage the infrastructure in certain countries due to rising sea-levels and extreme weather. These severe consequences put governments under increasing pressure from international bodies and non-governmental organizations (NGOs) to reduce emissions and define environmentally friendly economic growth plans.

This paper contributes to this newly emerging discussion about air quality and its essential consequences by building a new index of the air quality for 122 countries between 1985 and 2005. This index allows a comprehensive comparison of countries

[1] http://www.who.int/mediacentre/factsheets/fs313/en/

with respect to their local and global air quality and an evaluation of changes in air quality over time. It is also important for international organizations which closely monitor changes of air quality in their member states. Moreover, empirical researchers may be interested in such environmental performance measures for various cross-country studies analysing the relationship between air quality and a wide range of economic as well as socio-economic outcome variables such as the impact on institutions of the welfare state in general, health care cost in particular, and the quality of life.[2]

Most of the empirical literature focuses on explaining the relationship between a specific emission indicator and economic, political and demographic variables. A weak point of these studies is that they deal with only one indicator of air quality and as such determine the effects of the variables of interest on one indicator of air quality only. This may cause an errors-in-variables problem. We, however, use a Multiple Indicators-Multiple Causes (MIMIC) model taking into account potential measurement errors in the indicators of air quality and – most important – use two indicators for air quality simultaneously.[3] The advantage over traditional regression analysis is that it explicitly models measurement errors and can estimate parameters with full information maximum likelihood (FIML) providing consistent and asymptotically efficient estimates [Chang et al. (2009)]. Using sulphur dioxide (SO_2) and carbon dioxide (CO_2) emissions as indicators of air quality, we test which determinants have the most impact on the quality of the air and present a new comparative index of air quality. This index ranks 122

[2] This paper focuses on air quality due to data availability in this area. The empirical model can be easily extended to estimate broader concepts of environmental pollution, given the availability of data on other major indicators such as water pollution.

[3] MIMIC models have been applied to estimate the development of the shadow economy [see e.g. Dell'Anno and Schneider (2003), Schneider (2005), and Buehn (2011)] and corruption [Dreher et al. (2007)]. Promising recent applications of this methodology to smuggling are presented in Farzanegan (2009), Buehn and Eichler (2009), and Buehn and Farzanegan (2012).

countries according to their air quality and shows the development over the years 1985 to 2005.

Two other environmental quality indices, the Environmental Sustainability Index (ESI) and the Environmental Performance Index (EPI), have been built in the last decade. Both of them are composite indices using several environmental indicators to build a single environmental index. The EPI index is estimated for the years 2006, 2008, and 2010. However, changes in the methodologies and underlying data make it impossible to compare the EPI over time [Emerson et al. (2010)]. The ESI developers used 26 indicators to build this index, which is available for the years 2001, 2002, and 2005. The air quality index we present in this paper has two main advantages over the two existing indices. First of all, the country ranking by the air quality index can be compared from 1985 to 2005 as the underlying variables and the methodology is consistent over time. Second, the MIMIC methodology weighs the determinants of air quality according to their relative importance thus avoiding the critical points of the ESI, which uses equal weights for all 21 indicators [Jha and Murthy (2003)]. We finally contribute to the literature by focusing on a specific aspect of environmental degradation, i.e. air pollution, which has – to the best of our knowledge – not yet been done in the literature.

We find that the major factors influencing air quality are GDP per capita, energy efficiency, industrial production, urbanization and the share of the population in working age population as well as the electricity produced from coal sources. Highly developed countries of Western Europe and North America are on top of the air quality index, while transition and developing countries make up its bottom, which is also more heterogeneous.

The paper is organized as follows. Section 2 discusses the theoretical considerations for the selection of causes and indicators of air quality and presents testable hypotheses. Section 3 explains the MIMIC methodology. Section 4 presents the estimation results and the index of air quality. Section 5 finally concludes the paper.

2. Literature and Theoretical Considerations

The standard theoretical and analytical framework for the investigation of air quality in the literature is the theory of the Environmental Kuznets Curve (EKC). It explains how shifts of the economic structure, income-induced policy changes, demographic changes and political and economic institutions shape an inverted U–shaped relationship between economic growth and air quality. The MIMIC model we design is based on this theoretical framework, i.e. the selection of causal and indicator variables is based on the insights of the EKC theory and the related literature.

2.1 Indicators

Obviously, one would consider two main measures of local and global air pollution as indicators of the air quality index, the first one being

a) Indicator of local air pollution.

The main indicator of local air pollution is sulfur dioxide (SO_2), which causes acid rain degrading trees, crops, water, and soil.[4] Smith et al. (2011) provide annual estimates for the global and regional anthropogenic sulfur dioxide emissions from 1850-2005. The final SO_2 emission estimates are the sum of the SO_2 emissions from various sources such

[4] http://epi.yale.edu/Metrics/SulfurDioxideEmissions

as coal, petroleum, and biomass combustion, shipping bunker fuels, metal smelting, natural gas processing and combustion, petroleum processing, pulp and paper processing, other industrial processes, and agricultural waste burning. We use the log of per capita SO_2 emissions as one of the indicators. The second measure of air pollution would be

b) Indicator of global air pollution.

The main proxy for global emissions is carbon dioxide (CO_2). According to the World Bank's definition, CO_2 emissions stem from the burning of fossil fuels and the manufacturing of cement. Estimates of CO_2 also include CO_2 emitted during production processes and by the consumption of solid, liquid, and gas fuels and flaring. We use the log of CO_2 emissions per capita as the second indicator of air quality.

2.2. Causes

For clarity, the causes are grouped into three main categories: economic, demographic, and governance factors.

a) Economic factors

One of the most robust determinants of air quality is economic development measured by GDP per capita. Environmental quality is often seen as a normal good if not luxury good, meaning that the income elasticity of environmental quality is larger than zero or even than one. Hence, the society pays more attention to the quality of the environment and the level of pollution if income increases (see Beckerman (1992) for details).

While per capita energy consumption is higher in developed countries causing more environmental degradation, the Environmental Kuznets Curve (EKC) suggests that more development improves environmental quality once a certain income threshold has been passed as richer economies may use less pollution intensive technology in production processes [see Grossman and Krueger (1995)]. Furthermore, economic development reduces the relative importance of the industry/manufacturing sector and increases the services sector, which may reduce pollution and improve the quality of the environment [Jänicke et al. (1997)]. This non-linear relationship between economic development and environmental quality schematically shown in Figure 1 has been extensively studied in the literature, for example in Smulders and Bretschger (2000), Kelly (2003), Lieb (2004), Dinda (2005), and Brock and Taylor (2010).[5]

[Insert Figure 1 here]

Testing the EKC hypothesis requires including the GDP per capita and its square term in the empirical specification. If the estimated coefficient of GDP per capita is negative and statistically significant while the coefficient of the squared GDP per capita is not, the economy is in situation A. If the coefficient of GDP per capita is positive and statistically significant and the squared term of GDP per capita is significantly negative, the economy is in situation B. The economy is in situation C if the coefficient of GDP per capita is positive and statistically significant and the coefficient of the squared term is insignificant. We test the EKC hypothesis using the log and the squared log of real GDP per capita:

H1: There is an inverted U-shaped relationship between economic development measured by real GDP per capita and air quality.

We also test the environmental implications of energy efficiency. Increasing energy efficiency allows using energy more economically, which should decrease pollution, all

[5] Dasgupta et al. (2002) and Stern (2004) survey the literature on the EKC hypothesis.

other things being equal. We measure energy efficiency by the GDP per unit of energy use (GDP/energy use). The corresponding second hypothesis is:

H2: A higher level of energy efficiency reduces the air pollution, ceteris paribus.

The structure of the economy also impacts the quality of the air. A service-based economy is presumably less pollutive than an economy with a higher share of manufacturing and industry in GDP, which consumes more energy and has a higher level of negative externalities on the environment [Neumayer (2003); Dinda (2004)]. Hence, taking the industry share of an economy into account might help explaining the level of pollution and the air quality. We use the industry's value added to GDP to test hypothesis three:

H3: A higher share of industry in GDP increases the air pollution, ceteris paribus.

Besides the degree of industrialization, the composition of a country's electrical power supply should impact the quality of the air. To test this hypothesis, we follow Neumayer (2003) and include the share of electricity production from coal sources in total electricity production. A high share of electricity produced from coal sources should on average reduce air quality. Likewise, the availability and use of alternative energy sources may contribute to a better quality and lower environmental pollution. We use the share of alternative and nuclear energy sources with respect to total energy use and hypothesize:

H4: A high share of electricity supply from coal sources leads to more air pollution, while a high share of electricity supply from alternative energy sources leads to less air pollution, ceteris paribus.

Another determinant of air quality is a country's degree of globalization and its international trade and investment profile. Cole (2004) suggests that trade openness may reduce pollution because countries may have easier access to environmentally friendly technologies. However, the opposite effect can also occur if developed countries export their “dirty” industries such as petrochemical and cement industries to developing countries, which usually have lower environmental standards and weaker environmental regulations. In such a scenario – known as the Pollution Haven Hypothesis – more trade openness would increase air pollution in the destination countries. To test the puzzling effect of trade on the environment, we use the share of imports and exports in GDP as a measure for trade openness. In addition to trade openness, we also test the effect of foreign direct investment (FDI) inflows. Foreign direct investors strive to maximize their profits and will allocate capital to the most profitable investments. Those may be located in developing countries not only because firms have lower production costs there due to the availability of cheap labor but also enjoy a lower amount of environmental standards and regulations, which significantly reduces production costs too. In this way, FDIs would support “dirty” industries and firms that circumvent environmental controls and higher environmental standards. Hence, FDIs can negatively impact air quality in the destination countries.

b) Urbanization and demographic factors

The impact of demographic factors such as the share of the urban population and the population density has also been studied in the literature. Urbanization impacts the environment too, although mixed effects can occur. On the one hand, urbanization may add to the environmental pollution as it leads to a raise in public and private transportation resulting in higher fossil fuel consumption [Panayotou (1997)]. Moreover, a higher degree of urbanization often implies a higher density of the means of production, having a further negative impact on the quality of the environment [Cole and Neumayer (2004)]. The negative consequences of urbanization might be mitigated by its own effects as it may stimulate networking activities among different groups of people and environmental NGOs, forcing governments to impose stricter environmental controls and standards on pollution intensive industrial units. Urbanization also provides a unique opportunity for people to access politicians and policy makers, which may be not the case in a country with a higher share of the rural population [Torras and Boyce (1998); Rivera-Batiz (2002); Farzin and Bond (2006)]. It is, however, unlikely that the benefits of urbanization outweigh its negative consequences. Hence, our fifth hypothesis is:

H5: A higher level of urbanization increases the air pollution, ceteris paribus.

Another variable measuring demographic aspects is the population density. There are two competing arguments explaining the effects of the population density on the environment. For instance, Seldon and Song (1994) show a negative effect of a higher population density on different indicators of pollution. They argue that environmental degradation is a less serious concern in sparsely but more densely populated countries. On the contrary, it is often emphasized that a high population density leads to an unsustainable exploitation of the environment [Hilton and Levinson (1998)]. We test this relationship in specification 5 of the MIMIC model estimations.

In addition to urbanization and the population density, the age structures of the population, in particular the share of the population in working age (15-64 years old), might influence environmental degradation. For example, Farzin and Bond (2006) point out that younger people can bear more pollution risks and have a lager option value waiting for future improvements of environmental quality as opposed to the older ones.

Older people may feel health problems caused by pollution more directly and are thus more willing to put pressure on the government for stricter environmental regulations. They may also have more spare time to participate in local NGOs, supporting environmentally friendly policies. We follow Farzin and Bond's line of argumentation and formulate the following hypothesis:

H6: A higher share of the population in working age increases air pollution, ceteris paribus.

We also control for the role of education. A better-educated society is expected to be more aware of environmental hazards and the related health problems [Bimonte, 2002); Farzin and Bond (2006); Pellegrini and Gerlagh (2006)]. Scruggs (1998) shows that a higher level of education and wealth is associated with pro-environmental policies across all countries. We use (gross) primary school enrolment as proxy for the level of education. Another factor, which we consider in our analysis, is income inequality. Torras and Boyce (1998) show theoretically and empirically that a more equal distribution of power – achievable through a more equal income distribution, wider literacy, and greater political liberties – can positively affect environmental quality.

c) Governance factors

The third group of factors that have attracted attention in the literature are factors measuring governance and the quality of institutions. Good governance is measured in many different ways such as low corruption, secure property rights, a strong rule of law, high government stability, good bureaucracy quality as well as democratic accountability. For example, environmental standards and regulations may not be effective in countries with rampant corruption, as bribe-taking corrupt bureaucrats make it easy to ignore environmental standards. A weak rule of law and an inefficient judicial system reduce the effectiveness of environmental regulations further. Although laws and regulations protecting the environment are in place, the lack of good institutions makes it easy to circumvent these regulations at a low risk of detection. Several papers show that democracy as well as civil and political freedom positively influence air quality, as preferences for environmental quality can be more effectively exercised in democracies than in dictatorships [see, for example, Panayotou (1997); Torras and Boyce (1998); Barrett and Graddy (2000); Harbaugh et al. (2002); Farzin and Bond (2006); Li and Reuveny (2006); Bernauer and Koubi (2009)]. We use the International Country Risk Guide (ICRG) indicators to measure the effect of different aspects of governance on the environment. Our final, more general hypothesis is:

H7: A better quality of institutions causes less air pollution, ceteris paribus.

3. Empirical Methodology

3.1. The MIMIC model of air pollution

This paper uses a MIMIC model to study the relationship between the quality of the air and its determinants. The key benefit of this approach is that more than one measure of air pollution can be taken into account at a time. Formally, the MIMIC model has two parts: a structural part and a measurement part. The structural model is given by:

$$\eta = \boldsymbol{\gamma}'\boldsymbol{x} + \varsigma \quad , \tag{1}$$

where η is the latent variable of air pollution, $\boldsymbol{x}$ is a q-vector of potential cause, and $\boldsymbol{\gamma}$ is a q-vector of coefficients in the structural model describing the causal relationships between air quality degradation and its determinants. The error term ς represents the unexplained component. The variance of ς is abbreviated by ψ and $\boldsymbol{\Phi}$ is the $(q\times q)$ covariance matrix of the causes $\boldsymbol{x}$.

The measurement model links the quality of the air to its indicators, i.e. air quality is expressed in terms of measurable variables assuming that the indicators chosen are sound measures of air quality. Formally, the measurement model is specified as:

$$\boldsymbol{y} = \boldsymbol{\lambda}\eta + \boldsymbol{\varepsilon} \quad , \tag{2}$$

where $\boldsymbol{y}$ is a p-vector of air pollution indicators, $\boldsymbol{\lambda}$ is a p-vector of coefficients indicating the expected change of the respective indicator for a unit change of air pollution, and $\boldsymbol{\varepsilon}$ is a p-vector of white noise disturbances with $(p \times p)$ covariance matrix $\boldsymbol{\Theta}_{\varepsilon}$. We use the logs of per capita SO_2 and CO_2 emissions as measures of air pollution. Thus, equation (2) results in:

$$\begin{bmatrix} \text{Carbon dioxide emissions} \\ \text{Sulfur dioxide emissions} \end{bmatrix} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \end{bmatrix} \times \begin{bmatrix} \text{Air pollution} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix}. \tag{3}$$

According to our theoretical considerations in section 2, we employ the following eight causes in the baseline specification of the structural model: real GDP per capita and its square, energy efficiency (GDP per unit of energy use), the share of industry in GDP, the production of electricity from coal, as well as a measure for the use of alternative energy sources, urbanization, and the share of the population in working age. Equation (1) thus results in:

$$\left[\text{Air pollution}\right]=\left[\gamma_1,\gamma_2,\gamma_3,\gamma_4,\gamma_5,\gamma_6,\gamma_7,\gamma_8\right]\times\begin{bmatrix}\text{GDP}\\ \text{GDP sq.}\\ \text{Energy efficiency}\\ \text{Industry}\\ \text{Electricty from coal}\\ \text{Alternative sources}\\ \text{Urbanization}\\ \text{Working population}\end{bmatrix}+\left[\varsigma\right]. \tag{4}$$

Figure 2 shows the baseline specification's path diagram, modeling air quality as air pollution. The small squares attached to the arrows indicate the expected signs of the coefficients.

[Insert Figure 2 here]

The coefficients are estimated by decomposing the MIMIC model's covariance matrix $\boldsymbol{\Sigma}(\boldsymbol{\theta})$ and finding values for the parameters $\boldsymbol{\lambda}$ and $\boldsymbol{\gamma}$ as well as the covariances contained in $\boldsymbol{\Phi}$, $\boldsymbol{\Theta}_\varepsilon$, and ψ that produce an estimate for $\boldsymbol{\Sigma}(\boldsymbol{\theta})$, $\hat{\boldsymbol{\Sigma}}=\boldsymbol{\Sigma}(\hat{\boldsymbol{\theta}})$ which is as close as possible to the sample covariance matrix $\boldsymbol{S}$ of the observable causes and indicators, i.e., of the $\boldsymbol{x}$'s and $\boldsymbol{y}$'s. The estimation procedure deriving the parameters minimizes the following fitting function:

$$F=\ln\left|\boldsymbol{\Sigma}\left(\boldsymbol{\theta}\right)\right|+tr\left[\boldsymbol{S}\boldsymbol{\Sigma}^{-1}\left(\hat{\boldsymbol{\theta}}\right)\right]-\ln\left|\boldsymbol{S}\right|-(p+q)\ . \tag{5}$$

In addition to the baseline specification shown in Figure 2, we estimate 10 specifications testing the influence of trade openness, FDI inflows, and population density as well as socio-economic and institutional factors such as inequality and good governance on air quality. Once the hypothesized relationships have been tested and the parameters have been estimated, the MIMIC model estimation results are used to calculate scores η_k for each country in the sample. This index then provides a ranking based on negative effects on air quality.

4. Results

Data has been collected every five years over the period from 1985 to 2005 and analyzed in a pooled cross-section, which is motivated by data availability. In addition, most variables included in the empirical model are not available before 1985 and not yet available for 2010. Table A.1 in the appendix presents a complete description of the variables as well as sources and also summarizes the expected correlations. When estimating a MIMIC model, one of the indicators of the latent variable has to be normalized. Typically, the variable with the highest factor loading is chosen for this purpose.[6] Following this practice, we chose to normalize CO_2 emissions to a value of 1, resulting in a standardized coefficient of 0.95 in the baseline specification 1. The MIMIC model estimations in Table 1 report standardized coefficients, as they indicate the response of air pollution in units of standard deviation for a one standard deviation change in an explanatory causal variable, all other variables remaining unchanged (Bollen [1989]).[7] The second indicator, SO_2 emissions, turns out to be significantly positively correlated to the latent variable of air pollution, which is in line with our expectations and economic intuition.

The baseline specification (1) is an estimation that includes only significant causes. Altogether, eight variables turn out to be significant, among them are variables describing economic and demographic conditions. With respect to the variables measuring economic conditions, we find a significant positive correlation for the GDP per capita and a significant negative correlation for its squared term. Energy efficiency is negatively correlated to air

[6] The choice of the normalized variable has no effect on the estimation results [Bollen (1989)].
[7] LISREL® Version 8.80 is used for estimation. The standardized coefficients are calculated as $\hat{\gamma}^{s}_{ji} = \hat{\gamma}_{ji}\sqrt{\hat{\sigma}_{ii} / \hat{\sigma}_{jj}}$, where the subscript s indicates the standardized coefficient, i denotes the causal, and j the latent variable. $\hat{\sigma}_{ii}$ and $\hat{\sigma}_{jj}$ are the predicted variances of the ith and jth variables, respectively.

pollution, while the correlation of the industry share in GDP is as expected positive. Urbanization and the population in working age have a strong adverse effect on air quality. While a higher share of electricity production from coal negatively effects the environment, the availability of alternative energy sources reduces the air pollution. Summing up, we conclude that all significant causes have the expected and plausible sign. Comparing the magnitude of the effects, the GDP per capita and its square are by far the most important determinants of air quality, strongly supporting the EKC hypothesis.

[Insert Table 1 about here]

Specification (2) uses the service sector's value added to GDP instead of the industry sector's value added and may be seen as robustness check. As one would expect, the correlation between the share of the service sector in GDP and air pollution is negative. That is, countries with more service-based economies tend to have lower levels of environmental degradation, all other things being equal. The specifications (3) to (11) report the results when one additional causal variable is added to the baseline specification. However, we find only a significant effect of bureaucracy on the quality of the air. We conclude that the MIMIC model confirms most of our hypotheses and fits the data fairly well, as indicated by the goodness-of-fit statistics in Table 1.

Using the estimations results of specification 1, we now build an index for the quality of the air for 122 countries by applying the coefficients of the significant causes to the corresponding observable variables as follows:

$$\text{Air pollution} = 3.21\cdot x_1 - 2.34\cdot x_2 - 0.27\cdot x_3 + 0.10\cdot x_4 + 0.1\cdot x_5 - 0.15\cdot x_6 + 0.1\cdot x_7 + 0.14\cdot x_8, \qquad (6)$$

where x_1 equals GDP per capita, x_2 equals the squared term of GDP per capita, x_3 equals GDP per energy use, x_4 equals the industry share of GDP, x_5 equals electricity produced from coal sources, x_6 equals energy produced from alternative energy sources, x_7 equals the share of the urban population, and x_8 finally equals the population in working age. This index is presented in Table 2; the higher the index value, the worse is air quality in a country in a particular year. We chose to order the countries according to the ranking in the year 1995 because index values could be computed for all 122 countries for that year, which is not possible for the other years due to missing values of certain causal variables.

[Insert Table 2 here]

The highly developed countries of Western Europe and North America are on top of the index. According to this index, the country with the best air quality is Norway, followed by Switzerland, Japan, Luxembourg, and Iceland. With the exception of Japan, the United States, the United Arab Emirates, and Canada, only Western European countries are among the top 15. At the bottom of the scale are Eritrea, Mozambique, Tajikistan, Ethiopia, and the Democratic Republic of Congo. These countries had, according to our index, the highest level of air pollution in 1995. As can be seen, the bottom of the index is more heterogeneous and encompasses developing and transition countries. A comparison of the indices for different time period shows interesting features. While the ranking of highly developed but slowly growing countries such as Germany and the Netherlands – they rank 16th and 17th in 1995 – is rather stable over time, other countries such as Luxembourg and Ireland whose economies grew strongly over the observation period experienced a steady improvement of air quality between 1985 and 2005, supporting the EKC hypothesis. In general, it seems that the ranking at the bottom of the index is more volatile than at the top.

5. Summary and Conclusions

The air quality index presented in this paper provides the first ranking for the quality of the air around the world from 1985-2005. We employ a MIMIC model that simultaneously deals with the causes and indicators of air pollution within a unified framework for 122 countries. This approach has important advantages. First, in contrast to existing empirical studies which use narrow concepts as a proxy of environmental performance, the MIMIC approach enables us to use the most relevant factors to explain the quality of the air. The empirical analysis shows a highly statistically significant influence of GDP per capita, energy efficiency, industrial value added, urbanization, and a higher share of the population in working age as well as the produced electricity from coal sources on air pollution. The standardized coefficients indicate that GDP per capita, energy efficiency, alternative (non-fossil) sources of electricity production, and the population in working age are the primary determinants. We provide strong evidence for the Environmental Kuznets Curve (EKC), i.e. the notion that air pollution increases at initial levels of economic development. After reaching a turning point, higher economic development, however, reduces air pollution. While a higher efficiency in energy consumption and a larger share of the service sector dampen air pollution significantly, a larger share of the industry sector in the economy, dependence on coal sources for the production of electricity, and a higher share of the urban as well as working population increase the environmental pollution. In addition to these variables, we have also controlled for trade, foreign direct investments, and governance factors to reduce the risk of an omitted variable bias in the estimations. However, the latter set of variables cannot explain air pollution beyond the first set of variables. The second advantage of the

MIMIC approach is that there is one ranking model for all countries which is tied to the causal variables that were used to estimate the model. As such, the model produces an index of air quality for a large sample of countries across different time periods. According to this, Luxemburg, Norway, Iceland, Switzerland, Japan, Sweden, the United States, Ireland, Denmark and Finland were the top ten countries in terms of air quality in 2005. On the other side, the Democratic Republic of Congo, Eritrea, Ethiopia, Togo, Nepal, Tajikistan, Ghana, Mongolia, Mozambique, and Tanzania were the ten countries with the worst air quality in 2005.

Countries that endeavour to improve air quality should invest more in green technologies of energy production. Increasing the share of non-fossil energy sources such as wind and nuclear energies reduces the environmental burden, too.

The air quality index based on the MIMIC approach is likely to be of interest for different user groups. One such group might be the policy-based academic community which evaluates the consequences of air pollution. Since the index derived in this paper renders a cardinal ranking for the quality of the air across countries, it may be used to provide reliable estimates of its impact on various economic or social indicators. Non-government organizations may also make use of the air quality index to monitor how the quality of the environment varies over time and evaluate a country's efforts to improve environmental standards.

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Table 1. *Results of the MIMIC model estimations (standardized coefficients)*

Specification	1	2	3	4	5	6	7	8	9	10	11
Causes											
GDP	3.21***	3.79***	3.15***	3.27***	3.20***	3.37***	3.20***	3.19***	3.21***	3.22***	3.25***
	(8.73)	(11.60)	(8.56)	(8.85)	(8.70)	(8.30)	(8.69)	(8.68)	(8.73)	(8.89)	(8.59)
GDP sq.	-2.34***	-2.83***	-2.29***	-2.41***	-2.34***	-2.49***	-2.34***	-2.34***	-2.34***	-2.42	-2.40***
	(6.72)	(9.11)	(6.59)	(6.85)	(6.71)	(6.48)	(6.68)	(6.73)	(6.73)	(6.99)***	(6.55)
Energy efficiency	-0.27***	-0.29***	-0.27***	-0.27***	-0.27***	-0.27***	-0.27***	-0.27***	-0.27***	-0.26***	-0.27***
	(8.37)	(8.97)	(8.28)	(8.43)	(8.16)	(8.41)	(8.34)	(7.97)	(8.26)	(8.13)	(8.20)
Industry	0.10***		0.10***	0.10***	0.10***	0.10***	0.10***	0.10***	0.10***	0.11***	0.10***
	(3.37)		(3.39)	(3.48)	(3.25)	(3.42)	(3.17)	(3.40)	(3.36)	(3.64)	(3.39)
Electricity from coal	0.10***	0.10***	0.11***	0.10***	0.10***	0.10***	0.10***	0.10***	0.10***	0.09***	0.10***
	(3.49)	(3.55)	(3.66)	(3.63)	(3.34)	(3.57)	(3.45)	(3.31)	(3.50)	(2.93)	(3.46)
Alternative sources	-0.15***	-0.16***	-0.15***	-0.14***	-0.16***	-0.15***	-0.15***	-0.16***	-0.15***	-0.15***	-0.15***
	(5.13)	(5.23)	(4.90)	(4.78)	(5.11)	(4.94)	(4.97)	(5.10)	(5.08)	(5.19)	(5.11)
Urbanization	0.10**	0.10**	0.10**	0.10**	0.09**	0.10**	0.10**	0.10**	0.10**	0.11***	0.10**
	(2.38)	(2.39)	(2.50)	(2.31)	(2.06)	(2.45)	(2.37)	(2.38)	(2.34)	(2.69)	(2.37)
Working population	0.14***	0.14***	0.13***	0.14***	0.15***	0.14***	0.14***	0.14***	0.13***	0.13***	0.13***
	(3.36)	(3.36)	(3.21)	(3.37)	(3.20)	(3.43)	(3.36)	(3.40)	(3.21)	(3.34)	(3.14)
Services		-0.11***									
		(2.97)									
Trade			0.03								
			(1.14)								
FDI inflows				0.03							
				(1.19)							
Population density					-0.02						
					(0.11)						

Primary school enrolment						-0.03 (0.93)					
Inequality							0.00 (0.13)				
Corruption								0.02 (0.50)			
Government									0.01 (0.21)		
Bureaucracy										0.08** (1.99)	
Law and order											0.02 (0.52)
Indicators											
CO_2 emissions	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.96	0.95
SO_2 emissions	0.75*** (12.56)	0.75*** (12.50)	0.75*** (12.54)	0.75*** (12.54)	0.75*** (12.61)	0.75*** (12.59)	0.75*** (12.57)	0.75*** (12.54)	0.75*** (12.56)	0.75*** (12.56)	0.75*** (12.57)
Goodness-of-fit indices											
Observations	139	139	139	139	139	139	139	139	139	139	139
Degrees of freedom	39	39	49	49	49	49	49	49	49	49	49
Chi-square (p-value)	37.35 (0.55	37.45 (0.54)	37.96 (0.87	37.95 (0.87)	40.91 (0.79)	37.51 (0.88)	40.82 (0.79)	38.08 (0.87)	37.40 (0.89)	37.58 (0.88)	37.34 (0.89)

Note: Absolute z-statistics in parentheses. * , **, *** indicate significance at the 10%, 5%, and 1% level, respectively. Estimation of the model requires the normalization of one of the elements of $\boldsymbol{\lambda}$ to an a priori value [Bollen (1989)]. The chi-square statistic tests the empirical model against the alternative that the covariance matrix of the observable variables is unconstrained. Smaller values indicate a better fit, i.e., a smaller chi-square does not reject the null hypothesis that the model reproduces the sample covariance matrix of causes and indicators. We cannot reject the null hypothesis of perfect fit for any of the estimated specifications as the *p*-values range between 0.54 (specification 2) and 0.89 (specifications 9 and 11).

Table 2. *The Air Quality Index for 122 Countries (1985:2005)*

Country	1985	Rank	1990	Rank	1995	Rank	2000	Rank	2005	Rank
Norway	-195.8	1	-200.1	3	-206.2	1	-212.4	2	-215.0	2
Switzerland	-	-	-206.6	1	-205.5	2	-209.7	3	-210.0	4
Japan	-192.4	3	-201.7	2	-204.9	3	-206.6	5	-209.0	5
Luxembourg	-177.2	8	-191.5	6	-201.6	4	-216.8	1	-222.3	1
Iceland	-195.3	2	-199.4	4	-198.2	5	-207.5	4	-214.9	3
United States	-183.9	6	-190.0	7	-192.9	6	-199.2	6	-202.5	7
Sweden	-186.9	5	-192.4	5	-191.9	7	-198.9	7	-204.3	6
France	-173.8	11	-181.1	9	-184.0	8	-189.4	9	-191.7	11
Denmark	-173.7	12	-176.9	13	-183.0	9	-191.3	8	-194.2	9
Austria	-172.9	13	-177.8	12	-181.7	10	-187.7	11	-189.3	14
United Arab Emirates	-190.9	4	-183.7	8	-180.3	11	-178.0	20	-181.3	19
Canada	-174.8	9	-178.3	11	-180.1	12	-185.4	14	-	-
Finland	-174.5	10	-180.6	10	-178.1	13	-188.3	10	-193.8	10
United Kingdom	-165.2	17	-171.8	18	-177.3	14	-185.6	13	-190.1	13
Belgium	-167.7	14	-174.0	14	-176.8	15	-183.2	16	-186.7	16
Germany	-165.4	16	-172.1	17	-176.7	16	-181.5	17	-183.2	18
Netherlands	-167.6	15	-172.6	16	-176.2	17	-184.2	15	-186.0	17
Hong Kong	-155.3	22	-166.8	20	-175.4	18	-181.4	18	-188.7	15
Brunei Darussalam	-179.6	7	-173.9	15	-174.8	19	-171.0	23	-169.6	22
Singapore	-149.3	23	-161.3	22	-173.3	20	-180.9	19	-190.5	12
Italy	-163.5	18	-169.6	19	-172.9	21	-177.3	21	-177.7	20
Kuwait	-	-	-	-	-170.9	22	-165.8	24	-	-
Ireland	-155.4	21	-161.0	23	-168.7	23	-186.5	12	-195.3	8
Australia	-159.0	19	-164.0	21	-166.9	24	-173.5	22	-177.4	21
New Zealand	-157.2	20	-157.7	24	-161.1	25	-163.6	26	-	-
Cyprus	-143.3	26	-154.0	25	-158.6	26	-163.7	25	-166.3	24
Spain	-144.0	25	-153.1	26	-155.4	27	-163.0	27	-166.9	23
Bahrain	-141.9	28	-144.1	28	-151.4	28	-	-	-	-
Portugal	-136.6	30	-144.0	30	-145.3	29	-153.0	28	-153.3	28
Greece	-143.2	27	-143.8	31	-145.1	30	-151.3	29	-159.4	26
Saudi Arabia	-148.1	24	-144.3	27	-144.9	31	-144.0	32	-145.3	30
Korea, Rep.	-118.3	38	-134.3	33	-144.6	32	-151.0	31	-159.5	25
Slovenia	-	-	-144.1	29	-142.9	33	-151.2	30	-158.6	27
Oman	-137.2	29	-135.2	32	-139.5	34	-140.4	33	-	-
Argentina	-130.9	32	-127.3	36	-137.2	35	-139.5	34	-140.5	31
Uruguay	-123.6	35	-129.2	34	-134.4	36	-137.8	35	-139.1	32
Trinidad and Tobago	-133.6	31	-127.9	35	-128.6	37	-135.6	36	-148.0	29
Mexico	-125.4	33	-125.0	38	-123.9	38	-130.5	37	-130.5	35
Venezuela	-120.7	36	-119.9	42	-123.8	39	-120.3	42	-120.6	45
Gabon	-124.1	34	-122.5	40	-120.7	40	-115.4	47	-113.4	51

Table 2 *continued*

Country	1985	Rank	1990	Rank	1995	Rank	2000	Rank	2005	Rank
Lebanon	-	-	-	-	-120.6	41	-120.2	43	-124.0	42
Slovak Rep.	-119.9	37	-122.8	39	-119.8	42	-128.2	38	-137.0	33
Costa Rica	-108.2	42	-112.0	46	-118.5	43	-123.9	39	-126.9	39
Czech Rep.	-	-	-116.9	43	-116.5	44	-119.6	44	-128.5	37
Croatia	-	-	-126.1	37	-116.5	45	-123.2	40	-130.8	34
Chile	-96.8	46	-101.1	52	-115.2	46	-119.2	45	-125.0	41
Panama	-115.2	39	-110.9	47	-115.1	47	-118.8	46	-122.9	43
Jamaica	-	-	-	-	-115.1	48	-113.8	51	-116.2	48
Brazil	-110.2	41	-110.7	48	-113.9	49	-114.0	50	-116.0	50
Hungary	-112.0	40	-115.9	44	-113.0	50	-120.8	41	-129.5	36
Malaysia	-97.6	45	-101.5	51	-112.4	51	-114.8	48	-116.6	47
Turkey	-102.3	43	-108.1	49	-110.3	52	-114.1	49	-120.0	46
Lithuania	-	-	-122.2	41	-105.2	53	-113.5	52	-127.3	38
Poland	-	-	-95.7	57	-100.5	54	-110.1	54	-116.1	49
Paraguay	-86.2	53	-96.3	55	-100.4	55	-100.3	59	-99.6	58
Colombia	-91.8	49	-96.2	56	-100.0	56	-99.0	61	-102.3	56
Namibia	-	-	-	-	-99.9	57	-101.4	57	-105.1	54
Latvia	-	-	-113.7	45	-98.3	58	-110.5	53	-125.6	40
South Africa	-101.0	44	-99.9	53	-97.8	59	-98.3	62	-101.8	57
El Salvador	-	-	-91.5	59	-96.9	60	-100.6	58	-104.0	55
Dominican Republic	-90.8	50	-91.3	60	-95.3	61	-103.0	56	-105.6	52
Estonia	-	-	-102.9	50	-94.9	62	-107.9	55	-122.8	44
Peru	-	-	-89.1	62	-94.0	63	-95.2	63	-99.1	59
Botswana	-80.2	56	-92.4	58	-93.3	64	-99.3	60	-105.3	53
Thailand	-71.0	64	-81.8	71	-92.9	65	-92.1	65	-98.1	61
Guatemala	-87.3	51	-88.3	63	-90.9	66	-	-	-91.3	67
Jordan	-95.9	47	-87.6	64	-88.0	67	-88.9	66	-94.3	63
Tunisia	-84.9	54	-85.4	67	-87.7	68	-93.8	64	-98.6	60
Algeria	-94.4	48	-91.0	61	-86.8	69	-87.4	67	-91.5	66
Romania	-	-	-87.2	65	-84.5	70	-83.9	72	-94.2	64
Iran	-86.4	52	-81.9	70	-83.0	71	-84.8	70	-89.3	69
Russia	-	-	-97.5	54	-83.0	72	-85.5	68	-96.0	62
Bulgaria	-79.0	57	-82.4	69	-82.4	73	-83.6	73	-92.9	65
Egypt	-77.0	59	-79.3	72	-80.8	74	-85.1	69	-86.6	72
Syrian	-76.9	60	-73.6	80	-80.7	75	-77.9	77	-79.3	78
Honduras	-78.7	58	-78.8	75	-78.8	76	-79.6	76	-82.8	75
Macedonia	-	-	-84.0	68	-77.2	77	-81.4	75	-83.1	74
Albania	-76.3	61	-73.5	81	-76.4	78	-84.1	71	-90.4	68
Congo, Rep.	-81.6	55	-78.0	76	-73.9	79	-71.8	83	-73.7	86
Morocco	-74.7	62	-76.6	77	-72.1	80	-74.0	79	-79.7	77
Philippines	-70.0	66	-72.9	82	-72.0	81	-72.2	82	-75.8	82

Table 2 *continued*

Country	1985	Rank	1990	Rank	1995	Rank	2000	Rank	2005	Rank
Bolivia	-70.4	65	-69.8	83	-71.8	82	-73.7	80	-76.2	81
Sri Lanka	-59.5	70	-62.2	90	-67.8	83	-72.9	81	-76.7	80
Belarus	-	-	-79.3	73	-67.5	84	-76.5	78	-87.8	71
Indonesia	-54.4	73	-57.9	93	-65.9	85	-62.6	88	-66.1	90
Kazakhstan	-	-	-	-	-65.7	86	-70.1	84	-84.6	73
Nicaragua	-	-	-	-	-64.7	87	-67.2	85	-69.4	87
Cote d'Ivoire	-69.1	67	-64.9	87	-62.1	88	-61.5	91	-58.0	95
Cameroon	-74.6	63	-67.1	86	-59.9	89	-61.8	90	-63.5	92
Pakistan	-53.1	74	-56.5	95	-59.1	90	-59.7	93	-62.3	93
Yemen	-	-	-56.9	94	-56.9	91	-57.8	97	-	-
Ukraine	-	-	-76.4	78	-56.2	92	-56.3	99	-68.6	88
Kenya	-55.6	72	-58.2	92	-56.0	93	-54.7	101	-55.8	96
Uzbekistan	-	-	-63.2	88	-55.8	94	-58.8	95	-63.8	91
Georgia	-	-	-86.1	66	-55.3	95	-64.9	86	-75.1	84
Zimbabwe	-59.5	69	-58.7	91	-55.1	96	-56.3	98	-50.1	104
Bosnia and Herzegovina	-	-	-	-	-55.1	97	-82.0	74	-88.3	70
Senegal	-56.6	71	-55.5	97	-54.3	100	-55.9	100	-58.2	94
China	-35.2	84	-41.3	106	-53.7	101	-63.2	87	-75.2	83
Azerbaijan	-	-	-79.0	74	-52.8	102	-59.4	94	-74.2	85
Armenia	-	-	-62.4	89	-52.4	103	-62.2	89	-77.9	79
Benin	-48.4	76	-45.8	100	-46.0	104	-48.6	104	-48.9	106
Sudan	-41.6	80	-43.3	104	-46.0	105	-48.8	103	-52.2	101
Zambia	-52.5	75	-49.4	99	-45.8	106	-47.0	108	-49.5	105
Moldova	-	-	-68.7	85	-44.7	107	-45.6	109	-55.2	98
Bangladesh	-41.9	79	-43.0	105	-44.6	108	-47.7	106	-51.4	102
Vietnam	-32.3	86	-37.5	109	-44.4	109	-49.9	102	-55.8	97
Kyrgyz Republic	-	-	-53.7	98	-43.5	110	-48.2	105	-51.3	103
Tanzania	-	-	-45.4	101	-43.3	111	-44.7	111	-48.8	107
India	-36.1	83	-39.9	107	-42.8	112	-47.7	107	-54.2	99
Cambodia	-	-	-	-	-41.6	113	-45.3	110	-52.9	100
Togo	-44.9	77	-43.6	103	-40.5	114	-41.2	113	-39.4	113
Mongolia	-44.3	78	-43.7	102	-39.9	115	-42.2	112	-46.5	109
Ghana	-37.4	82	-39.5	108	-39.6	116	-40.7	115	-42.9	110
Nepal	-34.3	85	-36.3	111	-38.2	117	-40.4	116	-41.8	112
Eritrea	-	-	-	-	-37.3	118	-34.5	117	-32.7	115
Mozambique	-29.5	87	-34.6	112	-35.7	119	-40.8	114	-47.2	108
Tajikistan	-	-	-56.1	96	-34.7	120	-33.6	118	-42.1	111
Ethiopia	-28.6	88	-30.3	113	-28.1	121	-29.4	119	-32.8	114
Congo, Democratic Rep.	-41.0	81	-37.5	110	-27.0	122	-20.5	120	-20.4	116

Figures

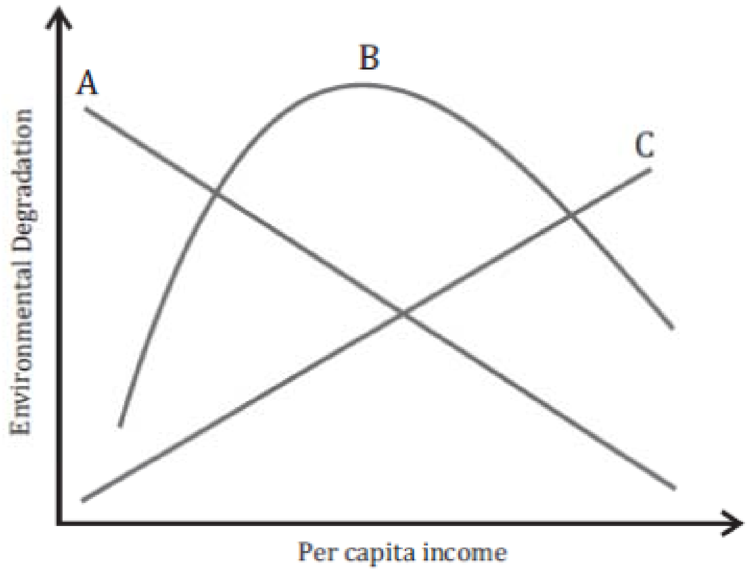

Figure 1. *Environmental degradation and economic development*

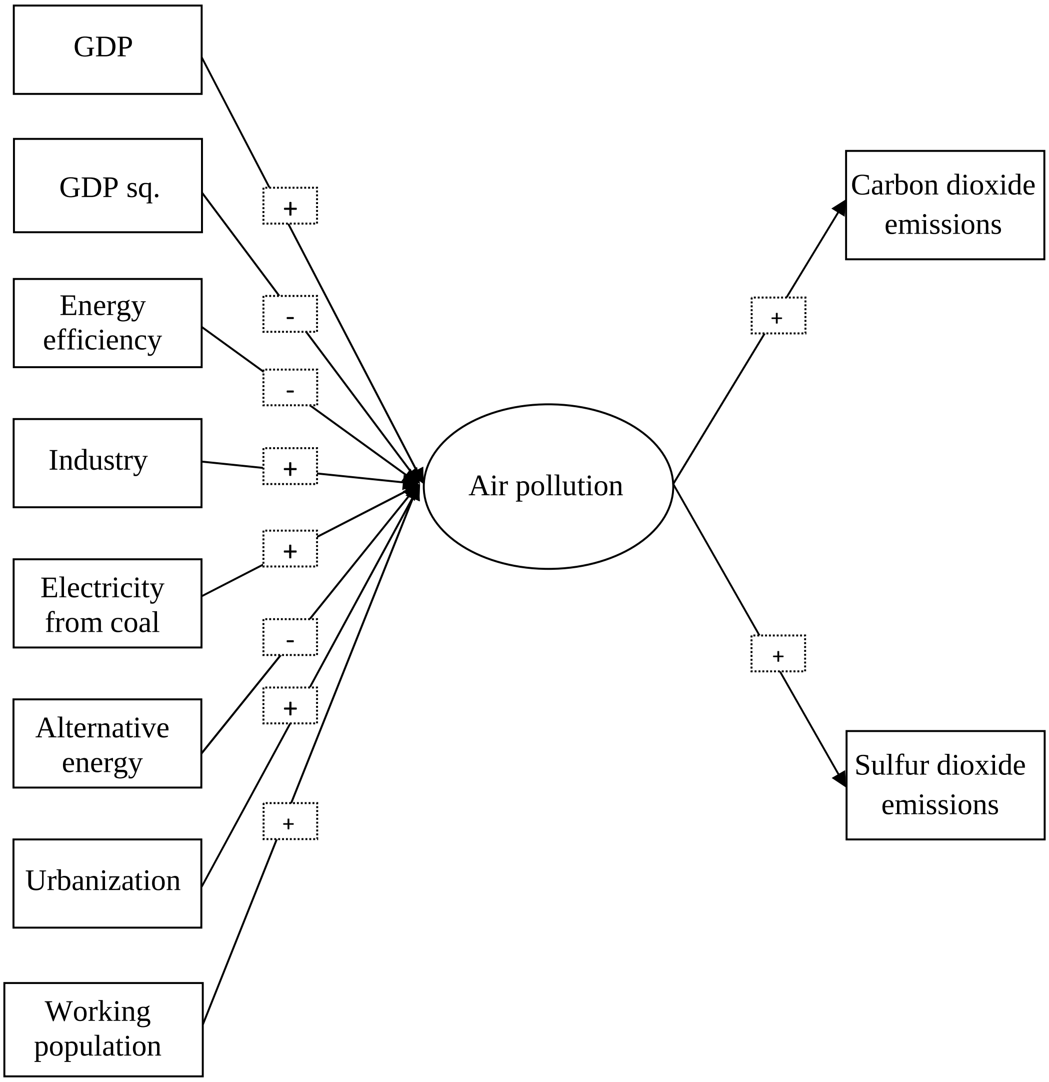

Figure 2. *Path diagram of the Air Quality Index (baseline specification)*

Appendix

Table A.1. *Variables, data sources, and expected correlations*

Variable	Definition and source	Expected correlation
Variables indicating air pollution		
CO_2 emissions	Log of carbon dioxide emissions per capita; Source World Development Indicators (WDI) 2010	+
SO_2 emissions	Log of sulfur dioxide emissions per capita; Source: Smith et al. (2010)	+
Variables considered as determinants of air quality		
GDP	Log of GDP per capita (constant 2000 US$); Source: WDI 2010	+
GDP sq.	Squared log of GDP per capita (constant 2000 US$); Source: WDI 2010	-
Energy efficiency	Log of GDP per unit of energy use (constant 2005 PPP $ per kg of oil equivalent); Source: WDI 2010	-
Industry	Industry, value added (% of GDP); Source: WDI 2010	+
Services	Service, etc., value added (% of GDP); Source: WDI 2010	-
Electricity from coal	Electricity production from coal sources (% of total electricity production); Source: WDI 2010	+
Alternative sources	Alternative and nuclear energy (% of total energy use); Source: WDI 2010	-
Urbanization	Urban population (% of total population); Source: WDI 2010	+
Working population	Population ages 15-64 (% of total population); Source: WDI 2010	+
Trade	Trade openness (exports + imports in % of GDP); Source: WDI 2010	Ambiguous
FDI inflows	Foreign direct investment, net inflows (% of GDP); Source: WDI 2010	Ambiguous
Population density	Log of population per sq. km; Source: WDI 2010	+
Primary school enrolment	Gross primary school enrolment rate; Source: WDI 2010	-
Inequality	UTIP-UNIDO wage inequality measure; Source: University of Texas Inequality Project (2004)	+
Corruption	Corruption index, higher index values indicate less corruption; Source: International Country Risk Guide	-
Government	Government stability index, higher index values indicate more stability; Source: International Country Risk Guide	-
Bureaucracy	Bureaucracy quality index, higher index values indicate a better quality; Source: International Country Risk Guide	-
Law and order	Law and order index; higher index values indicate a better outcome; Source: International Country Risk Guide	-