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Environmental Kuznets curve and sulfur emissions: a comparative econometric analysis

Abstract

This paper examines the relationship between economic growth and sulfur emission by testing the validity of the EKC hypothesis for selected countries under different econometric settings. The authors have focused on three different empirical models to obtain EKC for the countries in our dataset. The first model considers the impact of both the logarithmic form of GDP per capita and its square on the logarithmic form of sulfur dioxide (SO_2) per capita. In model 2, the authors extend model one by including the impact of trade intensity or openness variable on sulfur dioxide emission. Finally, the study investigates if there is a statistically significant impact of population density on sulfur dioxide emission. Estimation results have revealed that there is an inverted U-shape pattern between economic growth and sulfur emission per capita. Although most studies in the literature have found fixed effects as the appropriate estimation method, our estimations support the random effects model as the most suitable estimation method. Another important result is that both openness and population density play a significant role in sulfur emission. The openness of a country to foreign trade helps to the reduction of sulfur emission. On the other hand, population density variable has a positive but a minor effect on sulfur emission.

Keywords: environmental Kuznet's curve, economic growth, sulfur dioxide emission.
JEL Classifications: C33, Q53, Q58.

Introduction

Concerns about the environment have been increasing dramatically due to the environmental problems and their consequences. Much has been said and written on the relationship between economic growth and environmental degradation, yet nothing has been as close to the frontiers as the concept of Environmental Kuznets Curve (EKC) which emerged from the study that investigated firstly the relationship between economic growth and income inequality (Kuznets, 1955). However, the adaptation of this study to the environmental problems took place in the 1990s. One of the first works to investigate the relationship between economic growth and various environmental indicators showed an inverted U-shaped relationship, although EKC is not mentioned per se (Grossmann and Krueger, 1991)[1]. In a later work, the authors examine mainly the relationship between per capita income and various environmental indicators (Grossman and Krueger, 1995). Their study has employed a common methodology to investigate the relationship between the scale of economic activity and environmental quality for a broad set of environmental indicators using Global Environmental Monitoring Systems (GEMS) data. They estimated several reduced form equations that relate the level of pollution in a location (air or water) to a function of current and lagged income per capita in the country and to other covariates such as adummy variable for the location of the monitoring station, population density and time trends for air pollutants and mean temperature and time trend for water pollutants. They find an inverted U-shaped relationship between GDP and air pollutants (SO_2, SPM, and heavy particles).

To represent environmental degradation, several environmental indicators have been proposed by scholars. Here, we use sulfur emission as the major environmental indicator since it has local effects and has a longer-range dataset. Other pollutants, which have a global effect on the environment, follow a different pattern. The concentrations of these pollutants are increasing monotonically as per capita income increases. This result is not surprising as the decrease of global air pollutants is only possible when there is consensus on abatement.

Studies of the literature have tried to find the turning point, after which environmental degradation decreases as per capita income rises. Turning points in the literature have displayed great differences due to the data and empirical models employed. However, we can roughly say that turning points range between 3000 and 12,500 in 1990 PPP adjusted dollars. Thus, it is not an easy task to derive an approximate value for sulfur dioxide emission/concentration from the literature.

Another study estimates EKC for 10 different indicators of environmental degradation (Shafik and Bandyopadhyay, 1992). The sample includes observations from 149 countries for the period of 1960-1990. The study uses three different functional forms: log-linear, log-quadratic and a logarithmic cubic polynomial in GDP per capita and a time trend. Using a fixed effect model they find that air pollutants support the EKC hypothesis. The turning points for both air

[1] The EKC concept has emerged from three independent working papers (Dinda, 2004; see also Shafik, 1994; Grossman and Krueger, 1995; Cole et al., 1997).

pollutants have been found between \$3000-4000 in 1985 PPP adjusted dollars.

In the presence of four different environmental indicators (namely, SO_2, NO_x, SPM, and deforestation) and pooled time series and cross-sectional data in which the countries are grouped according to their income level, the estimated turning points are much higher compared to other studies (Selden and Song, 1994). These are \$8,709, \$11,217, \$10,289, \$5963 for SO_2, NO_x, SPM and CO in 1985 PPP adjusted dollars, respectively. With similar pollution variables (the fitted equations for three airborne pollutants are in logarithmic quadratics in income per capita) and only cross sectional data, the estimated curves have been found to conform to the EKC hypothesis (Panayotou, 2003). Turning points have been found as \$3000, \$5500, and \$4500 for sulfur dioxide, NO_x, and SPM in 1985 PPP adjusted dollars, respectively.

Some new environmental indicators such as CFCs, methane, municipal waste, energy consumption, and traffic volumes were used to extend previous empirical analysis to further examine the EKC behavior (Cole et al., 1997). Furthermore, the authors used the generalized least squares (GLS) estimation procedure instead of ordinary least square (OLS) in order to reduce heteroscedasticity and autocorrelation aiming to obtain more efficient estimates. The trade intensity (or openness) variable has not been found to be significant for any environmental indicator. Time trend was statistically significant for only seven of the environmental indicators cited. Turning points for sulfur dioxide are estimated as \$6,900 (in 1985 US dollars) and 5,700 (in 1985 US dollars) with respect to quadratic logs and quadratic levels model respectively. Their results support the EKC hypothesis mainly for sulfur dioxide and suspended particulate matter (SPM), which have low turning points. However, in a comprehensive EKC model of SO_2 and NO_x for 27 different countries for the period of 1975-1990 a panel data analysis revealed a significant impact of trade intensity variable on sulfur emission (Cole, 2003). The work estimates the EKC relationship for three air pollutants (sulfur dioxide, nitrogen oxides, and carbon dioxide) and a water pollutant (a measure of organic water pollution) using capital-labor ratio, trade intensity, and the interaction of both.

When the influence of income and the spatial intensity of economic activity on the sulfur dioxide concentration (rather than its emission) are examined, the panel data analysis showed that both economic activity and time trend have an impact on sulfur dioxide concentration statistically (Kaufmann et al., 1998). However, the results were criticized for using an unusual specification, which includes GDP per area and GDP per area squared variables (Stern and Common, 2001).

It is claimed that examining sulfur dioxide (SO_2) and (NO_x) emissions for the US states, using Environmental Protection Agency (EPA) dataset is superior to using GEMS data since EPA data is more reliable and covers long time period (i.e., from 1929 to 1994) (List and Gallet, 1999). Hence, the authors have asserted that EPA data could be more successful in capturing increasing and decreasing trends in EKC more easily. Turning points for quadratic and cubic income terms have been found relatively high and sulfur dioxide (SO_2) concentration is found to decreases around \$21,000 in 1987 US dollars.

To our knowledge, the most long-range time periods in the literature estimating EKC hypothesis for sulfur dioxide (SO_2) emission belong to two studies (Stern and Common, 2001, and Markandya et al., 2004). Both of these studies have used ASL dataset to examine EKC hypothesis. The former has estimated EKC hypothesis for OECD, non-OECD and world samples for the period 1850-1990. As a sulfur dioxide emission dataset, they used ASL and the Associates. The ASL data use a uniform methodology, so it can be poorer than the best individual country estimates in OECD database. Furthermore, the authors used as GDP 1990 international dollars (PPP), which is taken from Penn World Tables (PWTs). The authors have estimated a logarithmic quadratic EKC for OECD, non-OECD, and world samples. Both, the dependent (emission per capita) and independent (PPP GDP per capita) variables are in natural logarithms. The EKC has an inverted U-shaped pattern for the world as a whole in the aforementioned model. The turning point has been found to be high compared to other studies in the literature, i.e., \$101,166 in 1990 PPP dollars. As in the case of world sample, 23 OECD countries have an inverted U-shaped Kuznets curve. However, the overall rate of decline of this sample is very low and the turning point is \$9239, which is much lower than the world sample. On the other hand, non-OECD countries did not support the usual EKC hypothesis and these countries have an extremely high turning point.

The latter work using ASL and the Associates dataset estimates the EKC hypothesis of sulfur dioxide emission for 12 European countries from 1850 to 1999 (Markandya et al., 2004). The principal distinction of this study from the others is that it introduces fourth order polynomial of GDP as the explanatory variable for sulfur dioxide (SO_2) emission. The authors argue that EKC has two turning points. Hence, the countries should pass the second turning point in order to be clean with rising income. The study investigates the relationship between economic growth and sulfur dioxide emission (SO_2) in three steps. Firstly, the authors perform panel regressions of sulfur emissions against GDP and higher order terms of GDP. Secondly, they perform separate 'Ordinary Least Squares' (OLS) estimations for each of the 12 European countries. Finally, they performed regression using only the UK data of sulfur emission against GDP and higher order terms of GDP, as well as dummies for years in which new regulations were passed to restrict sulfur emissions. After the computation of panel data, the authors conclude that 4^{th} order polynomial is a better fit based on the compa-rison of adjusted R-squared with the quadratic one. Turning points of 4^{th} order polynomial are \$7,000 (in 1990 PPP dollars) and \$25,000 (in 1990 PPP dollars) for the first and second extremum points. Additionally, individual country regressions support a fourth order polynomial for all countries except Austria, Finland, Germany, Italy, and the Netherlands.

The objective of this study is to examine the relationship between economic growth and the sulfur emission and also to investigate the validity of the EKC hypothesis. The objective of this work is to examine the relationship between economic growth and sulfur emission by testing the validity of the EKC hypothesis for selected countries under different econometric settings. We have focused on three different empirical models in order to obtain EKC for the countries in our dataset. The first model considers the impact of both the logarithmic form of GDP per capita and its square on the logarithmic form of sulfur dioxide (SO_2) per capita. In model 2, we extend model one by including the impact of the trade intensity or openness variable on sulfur dioxide emission. Finally, we investigate if there is a statistically significant impact of population density on sulfur dioxide emission.

This paper consists of four sections. In section 1, we explain the data sources and explanatory variables comprehensively. In section 2, empirical models for sulfur emissions are established in accordance with the dataset available. Models have been established and necessary tests have been conducted in order to select the most suitable one. The final section concludes the paper.

1. Data source

This section provides detailed description of the variables used in this work. As explanatory variables, we use GDP per capita (in 1990 PPP dollars), trade intensity (or openness) and population density. However, other explanatory variables used in empirical studies will be discussed as well.

1.1. Total sulfur emission. We use Stern's sulfur emission data[1] (Stern, 2003). Sulfur dioxide (SO_2) data estimates are obtained in two ways: (1) by compiling available data from published sources; (2) by using a decomposition model, the first differences Kuznets curve model or simple extrapolation of the growth rate of emissions in order to complete the unavailable data. The primary source of the data used in Stern's study is ASL and the Associates (Lefohn et al., 1999). This dataset covers sulfur emissions for individual countries from 1850 to 1990. The ASL dataset is developed by using a common methodology for all years (from 1850 – beginning of industrialization – to 1990) and countries (234 countries) (Lefohn et al., 1999). The estimation method has taken into account the net production of the country (i.e. production plus imports minus exports), the sulfur content and the release factor. The net production figure is calculated by adding the extraction of sulfur bearing fuels and metals within a country and the imports of that country and then by subtracting the exports from the previously mentioned two figures. The production database includes emissions of sulfur from burning hard coal, brown coal, and petroleum, and sulfur emissions from mining and smelting activities. Sulfur content has been thought to depend on the country and type of fuel/metal used or mined in that country. Sulfur release or sulfur retention can be defined as the fraction of the sulfur in fuels or metals released to the atmosphere (Lefohn et al., 1999).

1.1.1. Estimating emissions for the 1990s. In order to fill the gaps in the ASL dataset two procedures are followed (Stern, 2003). The first stepis to compile the data from other datasets. If this is not possible, one of the three methods is used in the second step: decomposition method or the first differences EKC method or growth rate method.

1.1.2. Compiling published estimates. Published estimates are available in time series form for around 70 countries in Europe, the former Soviet Union, North America, East and South Asia, and Australia (Stern, 2003). EMEP website published data is used for the countries in Europe[2]. Data for sulfur emission are available for 33 countries at this website including Turkey and Canada for the years 1980-1999. The US data are taken from the EPA website[3]. The data encompasses the years between 1970 and 2002. The sulfur dioxide estimates for Australia are taken from the Australian Greenhouse Office (Stern, 2003). The remaining data benefits from others' works: East and South Asian countries (Streets et al., 2000) and for the rest of the countries (Olivier and Berdowski, 2001). All the data is converted to metric tones of sulfur per year in order to express all the published data in common units (Stern, 2003).

[1] Available at http://www.rpi.edu/~sternd/datasite.html.

[2] http://www.emep.int/emis_tables/tab1.html.

[3] http://www.epa.gov/ttn/chief/trends/index.html.

2.1.3. Decomposition method. To estimate for the remaining countries and years missing in the published data, the decomposition method is used (Stern, 2003). This model estimates sulfur emissions for a country and year by using the following econometric model.

$$S_{it} = \gamma_i A_t \prod_{j=1}^{J} y_{jit}^{\alpha_j} \left(\sum_{k}^{K} \beta_k x_{it} \right) \varepsilon_{it} \ . \quad (1)$$

In equation (1), i indexes country, t indexes time. A_t represents a time specific effect and γ_i is used to denote country specific effect. a's, β's, γ's and A are coefficients, which are estimated by using nonlinear panel data estimation. In this model, it is assumed that the sum of α_j's is zero[1].

1.1.4. First differences EKC method. When there are insufficient data to make use of decomposition method, fixed effects global estimate of Environmental Kuznets Curve (EKC) in first differences quadratic logarithms is utilized to fill the gaps in the dataset. The following equation gives the econometric model (Stern, 2003).

$$\Delta \ln\left(S_{it} / P_{it}\right) = \alpha_i + \gamma_t + \beta_1 \Delta GDP_{it} / P_{it} + \beta_2 \left(\Delta GDP_{it} / P_{it}\right)^2 , \quad (2)$$

where α_i and γ_t represent country and time specific effects, respectively. Furthermore, *GDP/P* is expressed in 1985 US dollars per capita adjusted for purchasing power parity (PPP dollars).

1.1.5. Growth rate method. If the above-mentioned two econometric models failed to estimate sulfur emission due to the lack of available data, the mean growth rate of sulfur emissions in the previous decade is used in the country to estimate the growth in emission. For the other cases, when data is available for some specific years, values are interpolated by using a simple linear curve (Stern, 2003).

1.1.6. Estimating emissions for 1850-2000. In order to maintain reasonably smooth time series for each country, the study computes backward estimation to get more accurate estimates in the following way: (1) periods for specific countries, which are missing in the original ASL dataset, are completed by using simple linear function; (2) the countries, which have alternative data sources for sulfur dioxide, are estimated by using growth rates method. For the other countries, the author uses unmodified ASL data; (3) the study extrapolates each country backward so that countries, which have missing data for years after 1850, are based on the growth rate of the region to which they belong; (4) finally, all the countries are grouped according to the appropriate regions. The extrapolations for each country with initial data missing for years after 1850 are based on the growth rate of the aggregate emissions for the region. It is argued that although this dataset is not the best for each individual country, it covers a long time period and estimates are not much different from other studies (Stern, 2003).

1.2. Per capita gross domestic product (GDP per capita). Per capita income serves to measure directly the relationship between economic growth and environmental quality. It also measures indirectly the endogenous characteristics of growth. Hence, the impact of rising industrialization and urbanization at middle income levels and the growing importance of services in high income economies are typical patterns that are represented by per capita income. Country specific per capita GDP data used in this work is benefited from other studies (Maddison, 2003)[2]. In cases of missing data, the gaps are completed by imputation (Maddison, 2003). The inclusion of the variables that directly measure urbanization or industrialization can generate multicollinearity problems (Shafik, 1994). Hence, these types of variables are not included into our empirical analysis of sulfur emission.

1.3. Trade intensity (openness). The ratio of the sum of exports and imports to the gross domestic product (GDP) can be defined as trade intensity or openness. Trade intensity (or openness) variable is taken from Penn World Tables (PWT's) (Summers and Heston, 1991). PWTs have taken the exports and imports figures from the World Bank and United Nations data archives. The openness data are calculated by using constant prices. However, it does not make difference using constant or real prices since openness is solely a ratio. The openness is used in this study to measure the impact of a country's foreign trade intensity on environmental quality.

1.4. Population density. Population density can be defined as the number of the people who fall into a square mile or kilometer area. This data is obtained from the World Resource Institute (WRI) web site[3]. In countries with low population densities there will be less pressure to adopt strict environmental standards or emissions since transportations in low population density countries will be higher. It is argued that societies tend to go through a similar pattern as in the case of EKC. Hence, it is suggested that the population density follows an increasing and then decreasing pattern as societies develop (Selden and Song, 1994).

[1] The countries and years, which are used in the decomposition model, first differences EKC method and growth rate method, are provided in Appendix A of this study.

[2] http://www.eco.rug.nl/~Maddison/.

[3] http://www.wri.org.

2. Empirical analysis

This section of the study presents the details of the empirical analysis. We explain the estimated models followed by estimation results.

2.1. The models. We focus on three different empirical models in order to obtain EKC for the countries in our dataset. In order to compute the panel data analysis for the countries, we generate a large Excel sheet, which includes all the explanatory variables. Prior to establishing the appropriate panel data model for the countries in our dataset, we compute linear regression for each country in order to detect countries, which comply with EKC hypothesis. Linear regression results have revealed that 19 out of 42 countries in our dataset support the EKC hypothesis in level forms and 22 out of them display an inverted U-shaped pattern in logarithmic forms. The countries, which show an inverted U-shaped pattern in logarithmic forms are: Austria, Belgium, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, the Netherlands, Poland, Spain, Sweden, the United Kingdom, Israel, Libya, Morocco, Syria, Tunisia, UAE, Brazil, Bulgaria[1]. Hence, we make use of logarithmic forms in our empirical models since taking logarithms of both sides of an equation eliminates huge differences between observations and can help for variance stability. We use twenty countries in our empirical analysis for all models. These countries are: Austria, Belgium, Denmark, Finland, France, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, Turkey, the United Kingdom, Egypt, Israel, Morocco, Argentina, Brazil, and Mexico.

The first model, which we propose, considers the impact of both logarithmic form of GDP per capita and its square on the logarithmic form of sulfur dioxide (SO_2) per capita. It is represented by the following equation:

$$\ln(S/P)_{it} = \alpha_i + \beta_1 \ln(GDP/P)_{it} + \beta_2 \ln(GDP/P)_{it}^2 + \varepsilon_{it}, \quad (3)$$

where S is sulfur emissions in tones of sulfur, P is population and ε is random error term α_i's country specific effects, and the countries are indexed by i and the time periods by t. In model 2, we have considered the impact of trade intensity or openness variable, T, additionally on sulfur dioxide emission. Model 2 is given by the following equation:

$$\ln(S/P)_{it} = \alpha_i + \beta_1 \ln(GDP/P)_{it} + \beta_2 \ln(GDP/P)_{it}^2 + \beta_3 T_{it} + \varepsilon_{it}. \quad (4)$$

Finally, in model 3, we have considered both the impact of trade intensity and population density, P/A, on sulfur dioxide emission and model 3 is given by the following equation:

$$\ln(S/P)_{it} = \alpha_i + \beta_1 \ln(GDP/P)_{it} + \beta_2 \ln(GDP/P)_{it}^2 + \beta_3 T_{it} + \beta_4 \frac{P}{A} + \varepsilon_{it}. \quad (5)$$

Furthermore, we compute model 1 both for 42 countries in our dataset for the time period of 1950-2000 and for the 20 countries for the time period 1951-2000 due to the data limitations, which is caused by trade intensity and openness variable. However, model 2 and model 3 are computed only for 20 countries from 1951 to 2000[2].

2.2. Estimation results for the panel data method. In order to get accurate and unbiased estimates, we perform heteroscedasticity and autocorrelation correction[3]. In this section, only estimation results for the models with heteroscedasticity and autocorrelation correction will be presented. Table 1 presents estimation results for all models and estimation methods after heteroscedasticity and autocorrelation correction.

As can be seen from Table 1, only estimation results for model 1 are computed for 42 countries for the time period of 1950-2000. Estimation results for other models are computed for 20 countries for the time period 1951-2000. GDP per capita and its square terms are observed significant for all models at 1% significance level both separately and simultaneously. However, openness variable is not significant for OLS estimation for models 2 and 3. Population density variable is not found significant for fixed effects estimation in model 3. Population density variable is found to be significant at 5% significance level for random effects estimation in model 3. All other explanatory variables in Table 1 are significant even at 1% significance level.

Another significant result is that all models comply with EKC hypothesis since logarithmic term of GDP has positive sign and its square has a negative sign for all models. However, in order to select the appropriate estimation method, we should utilize two specification tests. These specification tests are Breusch and Pagan's Lagrange Multiplier (LM) test and Hausman's specification test. Breusch and Pagan's LM test for the null hypothesis, which claims that classical regression, is better than one of the one factor panel models. If the null hypothesis is rejected, one of the one-factor panel models (fixed or

[1] See Appendix B for logarithmic scatterplot of sulfur per capita versus GDP per capita for the countries in our dataset.

[2] The aim of this procedure is to generate balanced dataset, which enables us to establish empirical models by the statistical software 'Limdep 7.0'.

[3] Estimation results for the models without heteroscedasticity and autocorrelation correction are given in Appendix C of this study.

random) has to be chosen in spite of pooled regression. On the other hand, Hausman's specification test is used to test the null hypothesis, which claims that random effects model is better than fixed effects model in estimation. Test statistics of Breusch and Pagan's LM test reveal that one of the one-factor panel models is better than the classical regression for all the models. Now, we have to select fixed or random effects model as the suitable estimation method. Results of Hausman's specification test reveal that random effects model has to be chosen in spite of fixed effects for all the models. This result proves that there is no correlation between error terms and explanatory variables.

Table 1. Model estimation results

Variables	Model 1[a]			Model 1			Model 2			Model 3		
	OLS	FE	RE	OLS	FE	RE	OLS	FE	RE	OLS	FE	RE
Constant	-40.601* (2.651)	-	-36.678* (1.936)	-54.345* (2.567)	-	-63.059* (2.405)	-56.079* (3.028)	-	-57.452* (2.807)	-54.452* (3.001)	-	-57.021* (2.817)
ln(*GDP*/*P*)	7.650* (0.619)	7.399* (0.722)	7.375* (0.453)	11.022* (0.598)	13.406* (0.841)	13.461* (0.548)	11.433* (0.709)	11.963* (0.886)	12.055* (0.658)	11.100* (0.702)	11.944* (0.887)	11.964* (0.660
ln(*GDP*/*P*)^2	-0.392* (0.036)	-0.416* (0.041)	-0.413* (0.026)	-0.601* (0.034)	-0.763* (0.047)	-0.764* (0.031)	-0.626* (0.416)	-0.670* (0.051)	-0.675* (0.038)	-0.610* (0.041)	-0.670* (0.051)	-0.671* (0.038)
Openness	-	-	-	-	-	-	0.001	-0.005* (0.001)	-0.005* (0.001)	$-7x10^{-4}$	-0.005* (0.001)	-0.005* (0.001)
Population density	-	-	-	-	-	-	-	-	-	0.001* ($2.7x10^{-4}$)	$5x10^{-4}$	0.001** ($7.5x10^{-4}$)
N	2100	2100	2100	980	980	980	980	980	980	980	980	980
R^2	0.27	0.75	0.27	0.46	0.75	0.46	-	0.75	0.46	-	-	0.47

Notes: [a]Denotes estimation results for 42 countries, *denotes significance level at 1%, **denotes significance level at 5%.

In Table 3.2, estimation results for these three different models are summarized. All the estimation coefficients are given with heteroscedasticity and autocorrelation correction. Standard errors have been given in parenthesis.

Table 2. Estimation results of models with heteroscedasticity and autocorrelation correction

Variables	Model 1[a]	Model 1	Model 2	Model 3
Constant	-36.678* (1.936)	-63.059* (2.405)	-57.452* (2.807)	-57.021* (2.817)
ln(*GDP*/*P*)	7.375* (0.453)	13.461* (0.548)	12.055* (0.658)	11.964* (0.660)
ln(*GDP*/*P*)^2	-0.413* (0.026)	-0.764* (0.031)	-0.675* (0.038)	-0.672* (0.038)
Openness	-	-	-0.005* (0.001)	-0.005* (0.001)
Population density	-	-	-	0.001** ($7.5x10^{-4}$)
RE/FE	RE	RE	RE	RE
N	2100	980	980	980
Turning point	$ 7481	$ 6657	$ 7556	$ 7350
R^2	0.16	0.46	0.46	0.475

Notes: [a]Denotes estimation results for 42 countries, *denotes significance level at 1%, **denotes significance level at 5%.

As can be observed from Table 2, adding extra explanatory variables do not contribute much to the explained part of the dependent variable. However, it is obvious that reduction of the countries in our dataset from 42 to 20 has increased R^2 value by a great amount. We can also conclude that standard errors do not change much, when we compare standard errors with and without heteroscedasticity and autocorrelation correction.

Turning points for the models have been calculated by taking derivatives with respect to logarithmic term of GDP and equation for that is given as follows:

$$\tau = \exp(-\beta_1 / (2\beta_2)) . \quad (6)$$

Turning points for model 2 and model 3 are found as $ 7556 and $ 7350 in 1990 PPP adjusted dollars respectively. These turning points seem very logical and are very close to turning points in other studies in the literature.

Conclusion

This study focuses on the investigation of EKC curve for the countries in our dataset. Estimation results reveal that there is an inverted U-shaped pattern between the economic growth and sulfur emission per capita. This result is in good agreement with most of the studies in the literature. Although most studies in the literaturefind fixed effects as the appropriate estimation method, the estimation results of this study support random effects model as the most suitable estimation method. Hence, it can be derived that there is no correlation between error term and explanatory variables. Another important result is that both the openness and the population density play a significant role on sulfur emission. The openness of a country to foreign trade helps the reduction of sulfur emission. On the other hand, population density variable has a positive but a minor effect on sulfur emission.

Generally speaking, the results of this study are as expected after heteroscedasticity and autocorrelation corrections are performed. Turning points for the models are very close to the other studies in the literature and are logical. Another significant result is related with standard error values. Although we use heteroscedasticity and autocorrelation corrections in models, there is not much change in standard error values. As a future study, other environmental indicators, which have local impact, can be used in order to test the validity of EKC hypothesis.

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Appendix A. Methods used to estimate emissions

In this section of the study, the three methods have been provided. When not otherwise specified, the data for the specific country and specific years are compiled from published sources (Stern, 2003).

1. **Decomposition method.** 1991-2000 Algeria, Asian Turkey, Bahrain, Argentina, Brazil, Egypt, Jordan, Mexico, Morocco, Tunisia, UAE, Yemen United; 1994-2000 Lebanon; 1995-2000 Romania; 1997-2000 Spain; 1998-99 Malaysia; 1999-2000 Greece, Portugal; 2000 Austria, Belgium, Bulgaria, Czech Republic, Denmark, European Turkey, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, the Netherlands, Poland, Slovakia, Sweden, the United Kingdom.
2. **First differences EKC method.** 1988-2000 Oman; 1991-1993 Lebanon; 1991-2000 Israel, Malta, Qatar, Syria; 2000 Czech Republic.
3. **Growth rates method.** 1991-2000 Iraq, Libya. When ASL data is not available, the actual Edgar estimates for 1990 and 1995 are used (Stern, 2003); 2000 Cyprus.

Appendix B. Logarithmic plots for the countries in the dataset

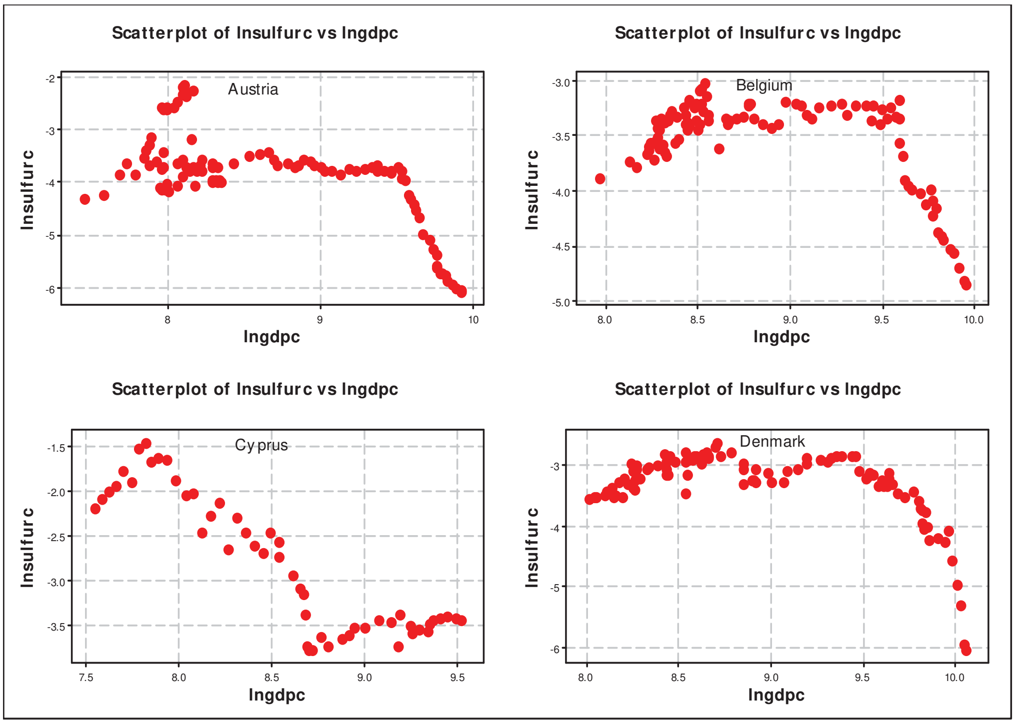

Fig. 1. Logarithmic scatterplot of sulfur per capita versus GDP per capita for Austria, Belgium, Cyprus and Denmark

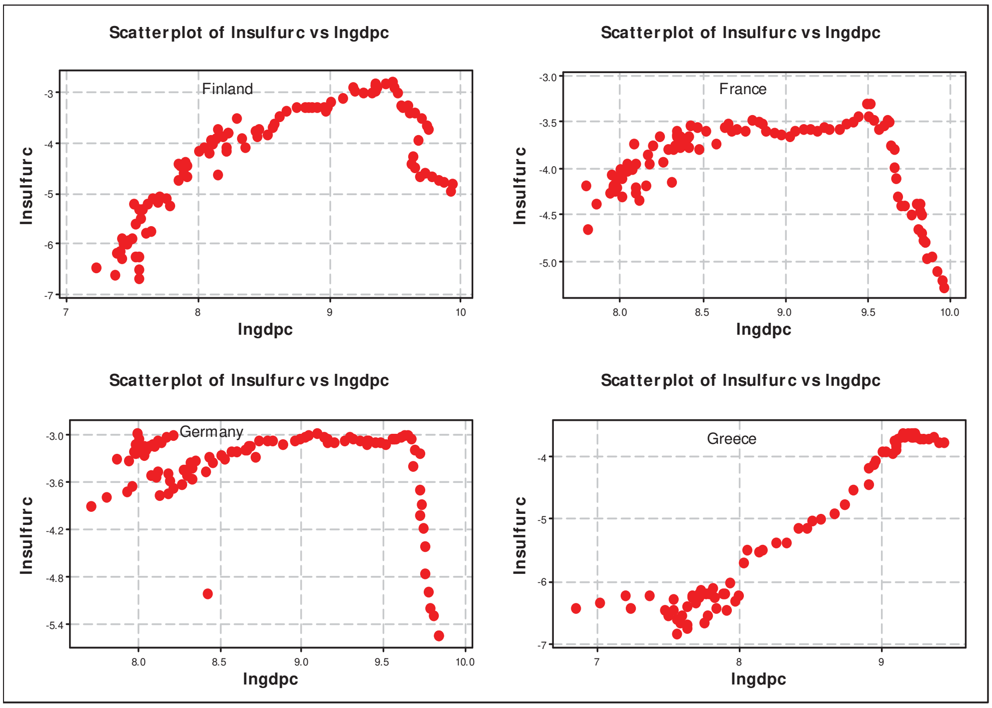

Fig. 2. Logarithmic scatterplot of Sulfur per capita versus GDP per capita for Finland, France, Germany and Greece

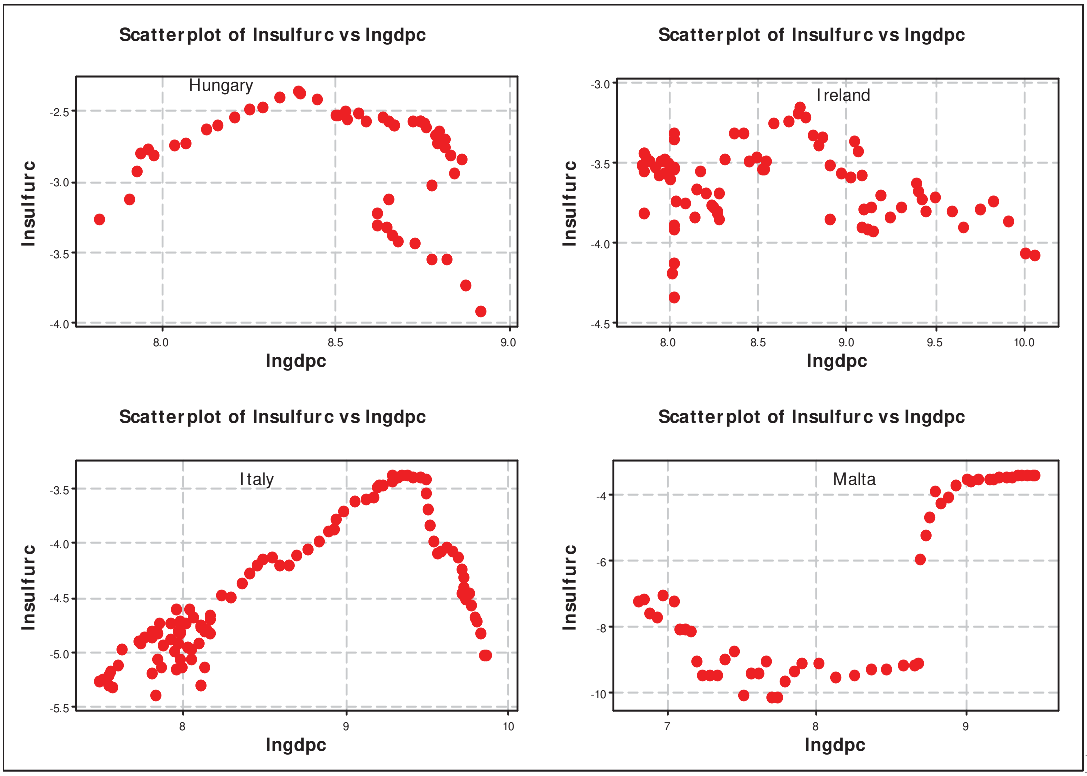

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Fig. 3. Logarithmic scatterplot of sulfur per capita versus GDP per capita for Hungary, Ireland, Italy and Malta

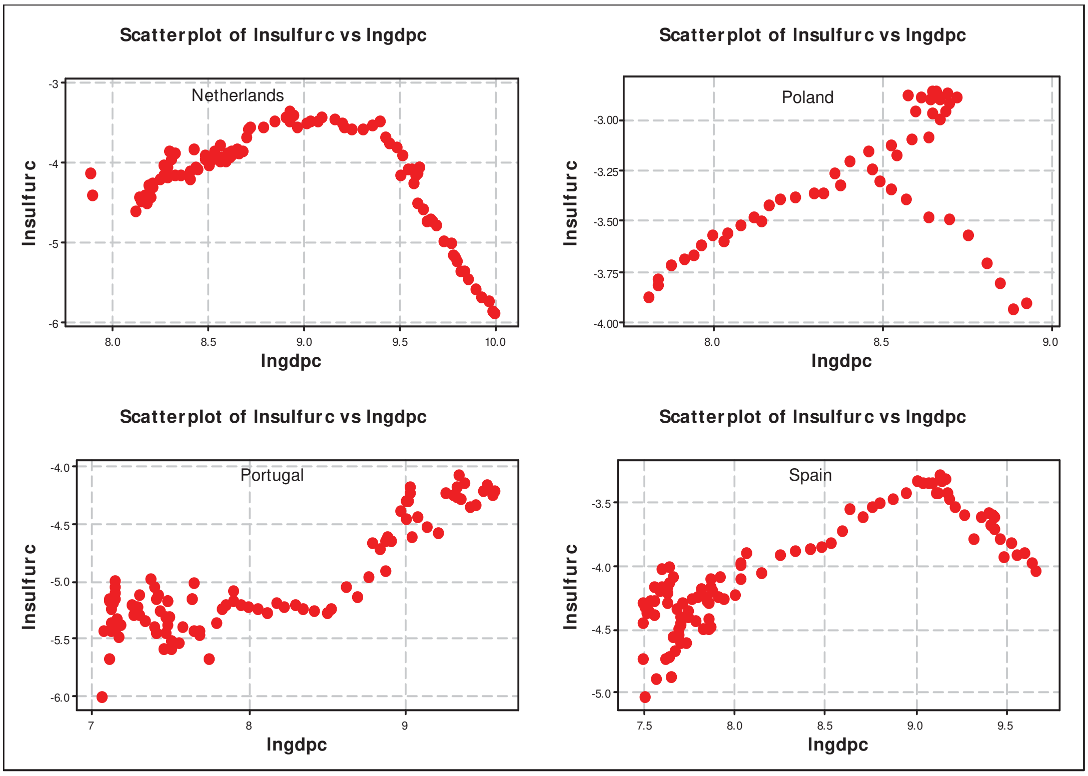

Fig. 4. Logarithmic scatterplot of sulfur per capita versus GDP per capita for the Netherlands, Poland, Portugal and Spain

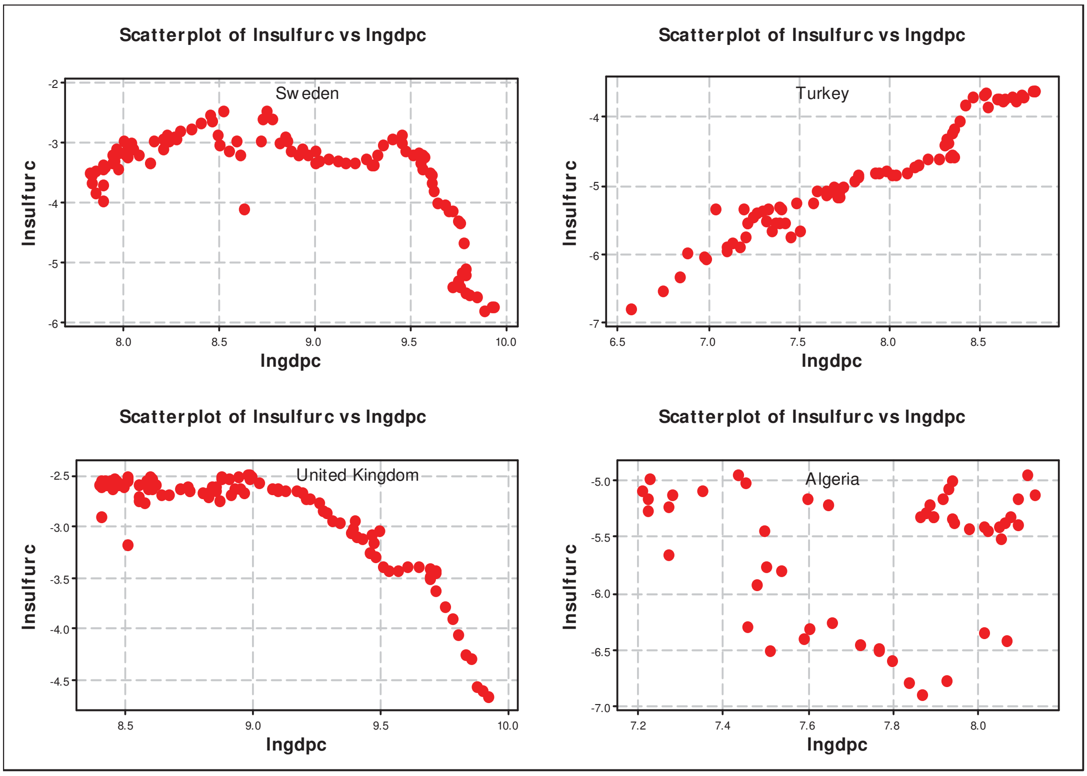

Fig. 5. Logarithmic scatterplot of sulfur per capita versus GDP per capita for Sweden, Turkey, the UK and Algeria

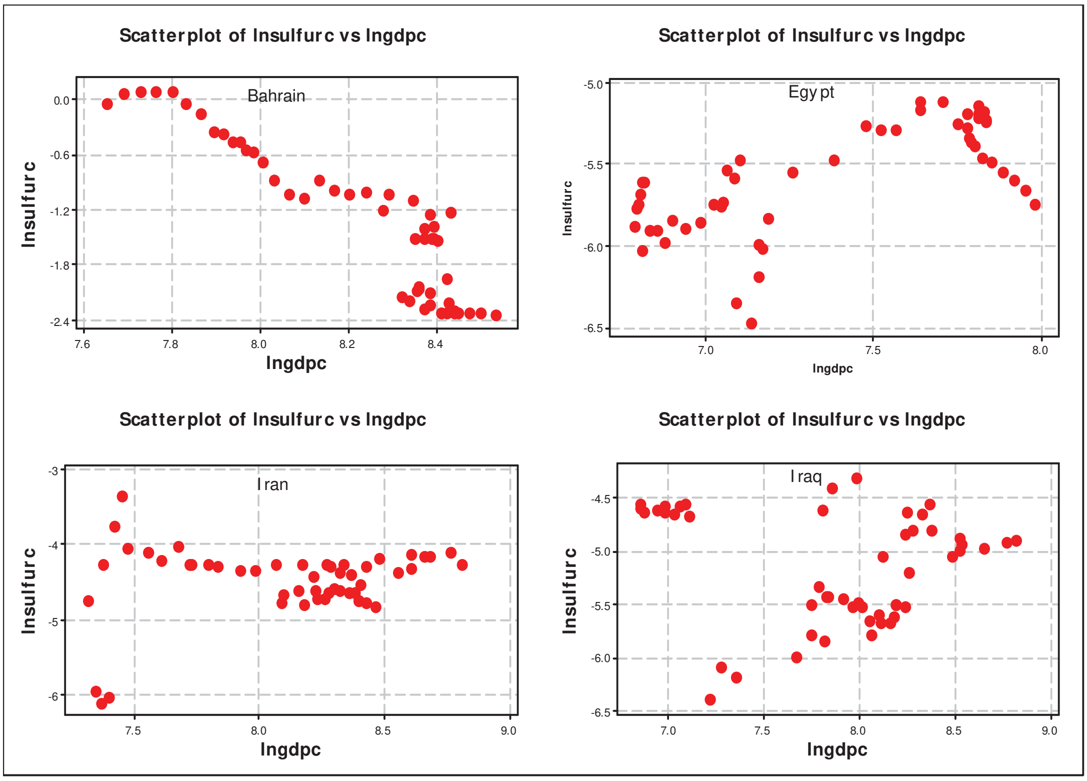

Fig. 6. Logarithmic scatterplot of sulfur per capita versus GDP per capita for Bahrain, Egypt, Iran and Iraq

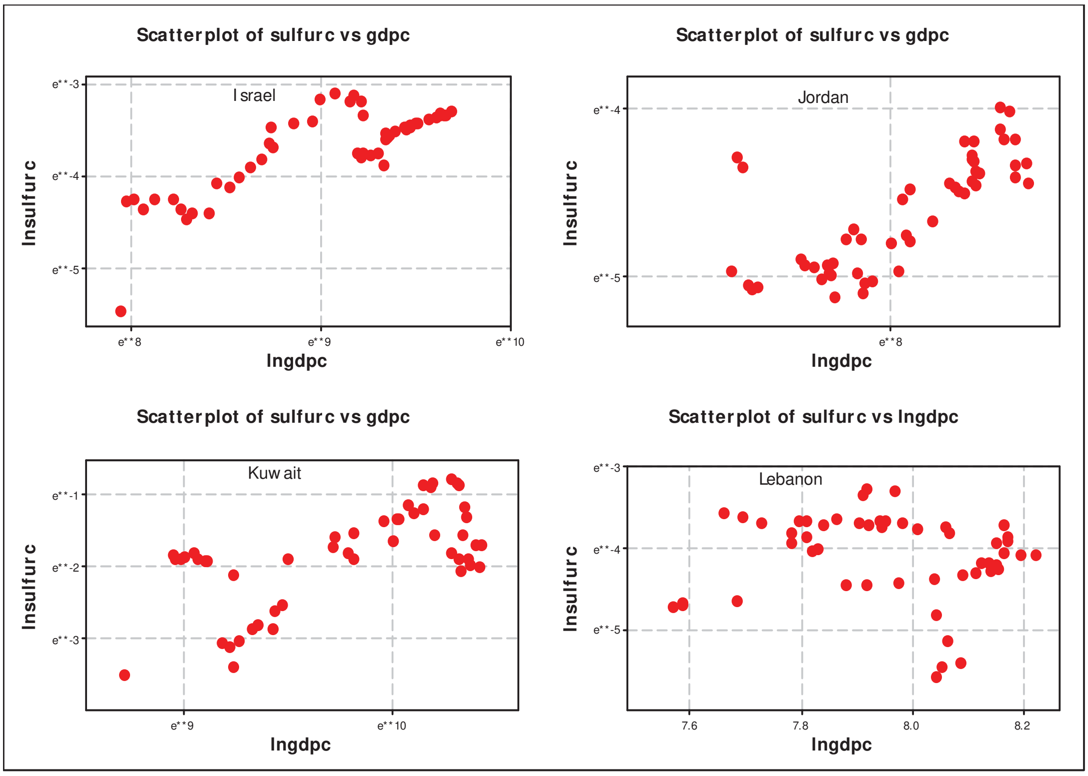

Fig. 7. Logarithmic scatterplot of sulfur per capita versus GDP per capita for Israel, Jordan, Kuwait and Lebanon

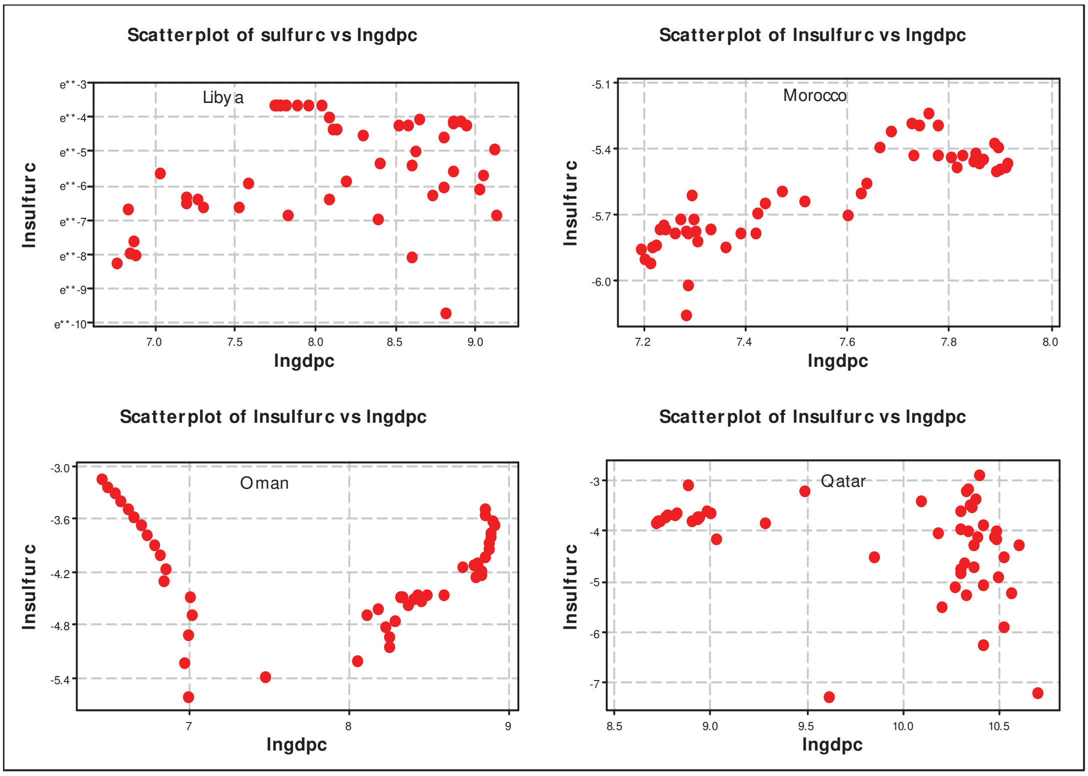

Fig. 8. Logarithmic scatterplot of sulfur per capita versus GDP per capita for Libya, Morocco, Oman and Qatar

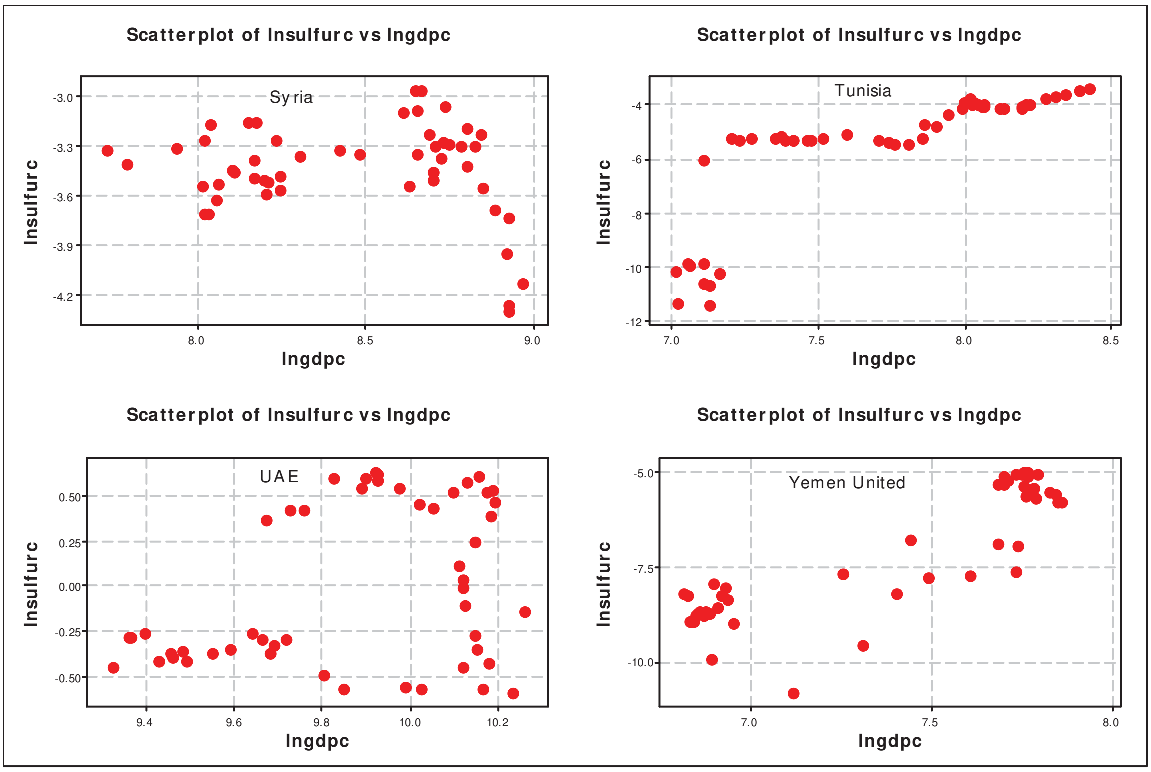

Fig. 9. Logarithmic scatterplot of sulfur per capita versus GDP per capita for Syria, Tunisia, UAE and Yemen United

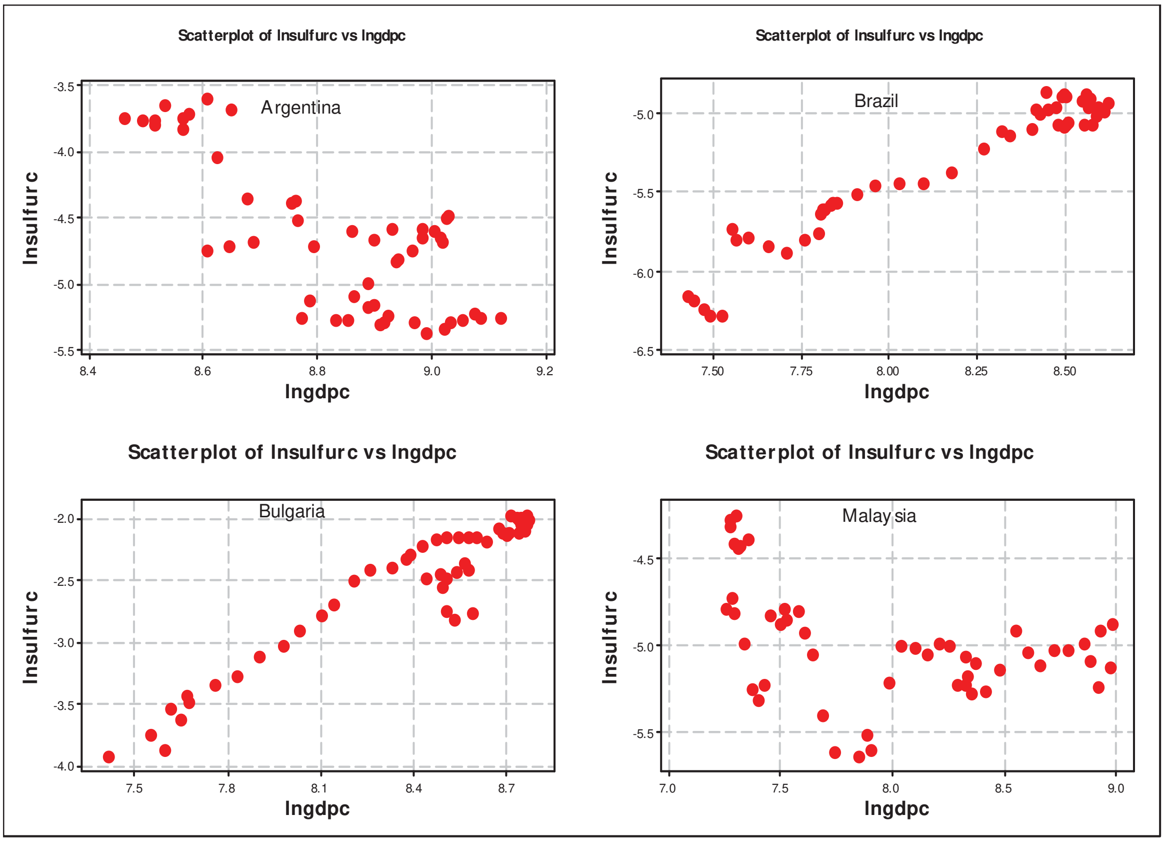

Fig. 10. Logarithmic scatterplot of sulfur per capita versus GDP per capita for Argentina, Brazil, Bulgaria and Malaysia

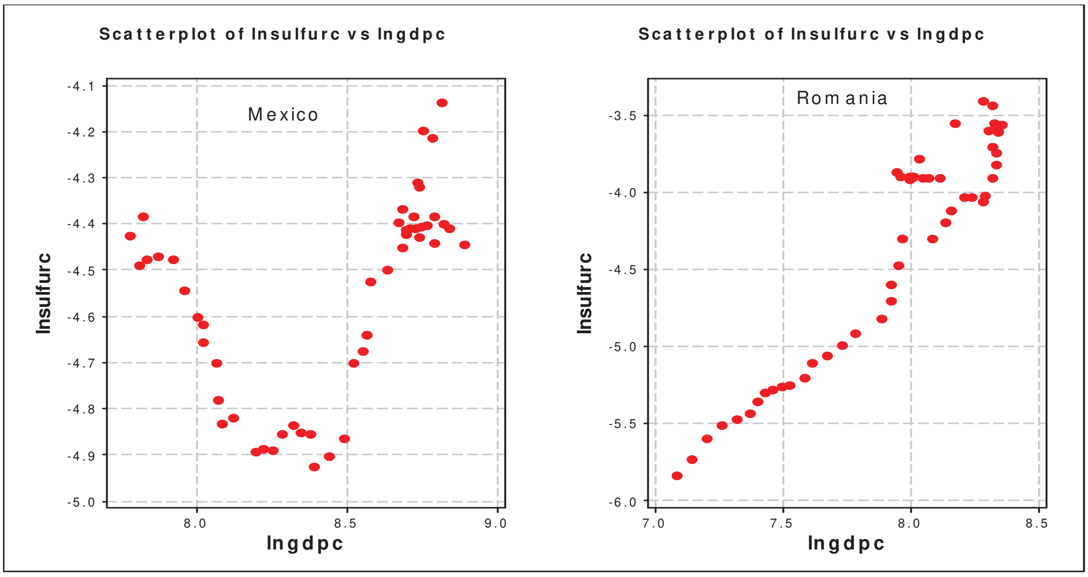

Fig. 11. Scatterplot of sulfur per capita versus GDP per capita for Mexico and Romania

Appendix C. Random estimations of models without heteroscedasticity and autocorrelation correction

Table C1. Random effects estimation of model 1 for 42 countries without heteroscedasticity and autocorrelation correction

Variables	Coefficient	Standard error	*t*-statistics	Probability
Constant	-36.254	1.903	-19.044	.0000
ln(*GDP*/*P*)	7.275	0.447	16.272	.0000
ln(*GDP*/*P*)^2	-0.407	0.026	-15.510	.0000

Table C2. Random effects estimation of model 1 for 20 countries without heteroscedasticity and autocorrelation correction

Variables	Coefficient	Standard error	*t*-statistics	Probability
Constant	-62.648	2.352	-26.634	.0000
ln(*GDP*/*P*)	13.367	0.537	24.892	.0000
ln(*GDP*/*P*)^2	-0.759	0.030	-24.832	.0000

Table C3. Random effects estimation of model 2 for 20 countries without heteroscedasticity and autocorrelation correction

Variables	Coefficient	Standard error	*t*-statistics	Probability
Constant	-57.452	2.807	-20.463	.0000
ln(*GDP*/*P*)	12.055	0.658	18.313	.0000
ln(*GDP*/*P*)^2	-0.675	0.038	-17.345	.0000
Openness	0.005	0.001	-3.798	.0001

Table C4. Random effects estimation of model 3 for 20 countries without heteroscedasticity and autocorrelation correction

Variables	Coefficient	Standard error	*t*-statistics	Probability
Constant	-57.021	2.817	-20.236	.0000
ln(*GDP*/*P*)	11.964	0.660	18.115	.0000
ln(*GDP*/*P*)^2	-0.672	0.038	-17.233	.0000
Openness	-0.005	0.001	-4.015	.0001
Population density	0.001	0.0007	2.073	0.0381