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An Empirical Study of Some Driving Factors of CO_2 Emissions: Evidence from Quantile Regression

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Abstract

A growing body of research has examined the determinants of CO_2 emissions. This literature has used mean-based regression methods in which only the mean effects of covariates are estimated. In this paper, we use the quantile regression methodology for a panel of 45 countries to investigate whether or not the factors that drive pollution do so in the same way for high and low pollution countries. The Environmental Kuznets Curve is confirmed and the positive effect of economic development is larger in low pollution countries. Energy consumption and financial development increase CO_2 emissions and their effects are larger in countries with lower levels of pollution. Industrialization increases pollution especially in countries with higher level of pollution. Openness to trade and urbanization are negatively related to emissions in low pollution countries. All these findings suggest that pollution control policies should be tailored differently across low and high pollution countries.

JEL classification numbers: C23, F18, O50, Q53
Keywords: CO_2 emissions, Energy consumption, GDP, trade openness, financial development, quantile regression.

1 Introduction

The climate change debate has drawn attention to the problem of greenhouse gases emissions into the atmosphere. All experts and governments throughout the world have called the international attention upon the negative consequences as well as upon the potential instruments to reduce greenhouse gases emissions, and particularly CO_2 emissions. The 21st session of the United Nations Conference of the Parties (COP21) held in Paris in December 2015 is a major milestone in efforts to reduce greenhouse gas emissions and combat global warming. All this calls for a clear identification of the driving forces of CO_2 emissions. A burgeoning literature has been accumulated during the last decade to uncover the driving factors behind CO_2 emissions. While some studies focused on the relationship between economic development and pollution by testing the validity of the Environmental Kuznets Curve (EKC) hypothesis, others have included into the nexus the impact of other relevant variables such as energy consumption, trade openness, financial development, foreign direct investment or urbanization.

Results from this literature are however mixed across countries and modeling techniques (e.g., Nahman and Antrobus, 2005; Smyth and Narayan, 2015 for reviews). For example, some studies provided evidence supporting the Environmental Kuznets Curve (EKC) hypothesis (e.g., Dinda and Coondoo,

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2006; Apergis and Payne, 2009; Jalil and Mahmud, 2009; Lamla, 2009; Iwata *et al.*, 2010) while many others found no support for this hypothesis (e.g., Dinda *et al.*, 2000; Halkos and Tsionas, 2001; Perman and Stern, 2003; Martinez-Zarzoso and Bengochea-Morancho, 2004; Galeotti *et al.*, 2006; Aslanidis and Iranzo, 2009 and Baek, 2015). It was found that the evidence regarding the EKC is sensitive to the econometric methods used. In a study consisting of 73 OECD and non-OECD countries, Halkos (2003) applied random coefficients and Arellano-Bond Generalized Method of Moments econometric techniques. The findings showed that the EKC hypothesis is not rejected in the case of the Arellano-Bond Generalized Method of Moments. On the other hand there is no support for the EKC hypothesis under the random coefficients model.

Furthermore, the evidence regarding the impact of some variables is unclear. For example, Antweiler *et al*. (2001) found that trade is good for the environment in a panel of 44 countries. In the case of Sub-Saharan Africa, Aka (2008) found that economic growth contributes to the degradation of air quality while trade is beneficial to the environment. Sharma (2011) found that GDP per capita and urbanization are two of the main determinants of CO_2 emissions in a panel of 69 countries. The effect of GDP per capita is positive while that of urbanization is negative. He also found that trade openness, per capita primary energy consumption and per capita electric power consumption have insignificant effects on CO_2 emissions. Akin (2014) found a positive relationship between CO_2 emissions, energy consumption and per capita income in a panel of 85 countries. Halkos and Tzeremes (2013) examined the carbon dioxide emissions–governance relationship for a panel of twenty largest economies (G-20). Using six governance measures, the findings reveal a nonlinear relationship between CO2 emissions and governance. They also reported that increasing the quality of countries' different governance factors does not always result to lower carbon dioxide emission levels. Finally, Sadorsky (2014) found that GDP per capita, population and energy intensity have positive impact on CO_2 emissions in emerging economies while urbanization is found to have no significant impact.

All these studies relied on linear regression models, which estimate the effects of the mean levels of explanatory variables on the mean level of pollution. We argue that it is informative to analyze the entire pollution distribution instead of just the mean level. This is more informative because the way in which factors affect pollution could be different in high pollution and low pollution economies. There may be some institutional differences between ‘dirty’ and ‘clean’ countries that might affect the determinants of pollution and the efficacy of local pollution reducing policies. Furthermore, it is possible that pollution feeds on itself particularly in countries where environmental protection policies are weak. This study tries to address the following question: are there different driving factors of pollution in high pollution countries compared to low pollution countries? If the answer to this question is affirmative, the findings will have important implications for pollution control policy which may have to be tailored differently for high pollution and low pollution countries.

To examine whether the existing level of pollution affects how the potential determinants of pollution come into play, this study uses the quantile regression methodology developed by Koenker and Bassett (1978). The advantage of this method relies in the possibility of investigating the effect of covariates at many points of the entire distribution of pollution level, not only at the mean but also in the tails. The remainder of the article is organized as follows. Section 2 outlines the estimation methodology and describes the data. Section 3 discusses the empirical results, while Section 4 concludes and gives some policy recommendations.

2 Model and econometric methodology

2.1 Model

Based on the existing literature, we specify the empirical model as follows:

$$CO_{2it} = \theta_0 + \theta_1 E_{it} + \theta_2 y_{it} + \theta_3 y_{it}^2 + \theta_4 Ind_{it} + \theta_5 F_{it} + \theta_6 T_{it} + \theta_7 U_{it} + \mu_{it} \quad (1)$$

where *i* is for country *i* in the panel, *t* refers to the time period, CO_2 stands for per capita carbon dioxide emissions, *E* is per capita energy consumption, *y* indicates per capita real GDP, y^2 is the square of per capita real GDP, Ind is industrial value added as share of GDP, *F* is financial development indicator, *T* is trade openness and *U* is urbanization rate.

The sign of θ_1 is expected to be positive because more energy use should result in more CO_2 emissions. The sign of θ_2 is expected to be positive whereas θ_3 is negative under the EKC hypothesis. If θ_3 is statistically insignificant, it implies an existing monotonic relationship between per capita income and CO_2 emissions. The sign of θ_4 is expected to be positive because an increase in the share of industrial sector should increase energy consumption and stimulate CO_2 emissions. A well-developed financial system may increase energy consumption through growth-enhancing effect. Furthermore, by making easier for consumers to borrow money, financial development increases the demand for more energy consuming durables goods such as automobiles, homes, refrigerators, air conditioners and washing machines (Sadorsky, 2011; Islam *et al.* 2013). Therefore, the expected sign of θ_5 is positive. The expected sign of θ_6 could be positive or negative depending on stage of economic development of country. In the case of developed countries, it is expected to be negative as countries develop, they reduce the production of pollution intensive goods and instead import these from other countries with less restrictive environmental protection laws (Jalil and Mahmud, 2009; Kohler, 2013). In the case of developing countries, the sign on trade is expected to be positive. However, international trade may allow access to energy-efficient technologies and better environmental management practices and thus contribute to significant reduction in energy consumption and pollution. The expected sign of θ_7 is positive as urbanization lead to higher demands for energy and exerts pressure on the environment.

2.2 The quantile regression methodology

The quantile regression method was first introduced by Koenker and Bassett (1978) and discussed in further works (see Koenker and Machado, 1999; Koenker and Hallock, 2001). This method has several advantages. First, compared to OLS regression, it is more robust to outliers. Second, it allows for the estimation of the effects of covariates at different points of the distribution of the dependent variable. Third, it is more robust to non-normality of residuals.

The quantile regression model can be formulated as follows:

$$q(CO_{2it} / \Omega_{it}) = \theta_0 + \theta_1 E_{it} + \theta_2 y_{it} + \theta_3 y_{it}^2 + \theta_4 Ind_{it} + \theta_5 F_{it} + \theta_6 T_{it} + \theta_7 U_{it} + \mu_{it} \quad (2)$$

where $q(CO_{2it} / \Omega_{it})$ is the conditional quantile of CO_2 emissions and Ω_t contains the available information known at time *t*. Eq. (2) can be written as follows:

$$Y_{it} = X_{it}\theta_\tau + \varepsilon_{it} \qquad (3)$$

where $X_{it} = \left(1, E_{it}, y_{it}, y_{it}^2, Ind_{it}, F_{it,}, T_{it}, U_{it}\right)$ is the vector of explanatory variables; θ_τ are the $k \times 1$ regression coefficients at the τ-th quantile of the dependent variable Y.

Contrary to OLS which is based on minimizing the sum of squared residuals, the τ-th quantile regression estimator of θ minimizes a weighted sum of absolute errors:

$$\min_\theta \left[\sum_{Y_{it} \geq X_{it}\theta_\tau} \tau \left| Y_{it} - X_{it}\theta_\tau \right| + \sum_{Y_{it} \leq X_{it}\theta_\tau} (1-\tau)\left| Y_{it} - X_{it}\theta_\tau \right| \right] \qquad (4)$$

The quantile regression method is less restrictive than the Ordinary Least Squares (OLS) approach as it allows the slope coefficient to vary across the quantiles of the dependent variable. The special case $\tau = 0.5$ which minimizes the sum of absolute residuals corresponds to median regression. The first quartile is obtained by setting $\tau = 0.25$. As one increases τ from 0 to 1, one traces the entire distribution of CO_2 emissions conditional on covariates.

2.3 Data and descriptive statistics

The empirical analysis uses data for 45 countries comprising 12 Sub-Saharan African countries, 10 American countries, 10 Asian countries, 5 European countries, and 8 MENA member countries. The list of countries is presented in Table 1. The countries were chosen based on data availability. We use annual time series for real GDP per capita expressed in constant 2005 US dollar, per capita energy consumption in kg oil equivalent, per capita CO_2 emissions measured in metric tons, industrial value added as share of GDP, domestic credit to private sector provided by banks as share of GDP as the proxy for financial development, trade openness measured as ratio of exports plus imports of goods and services to GDP, and urbanization measured as the share of the urban population in total population. All the data cover the period from 1980 to 2011 and are obtained from the 2015 World Development Indicators by the World Bank. The sample period has been dictated by availability of the data for all the series. All the data were converted into natural logarithms.

Table 1: List of countries and sample period

Regions	**Countries**	**Sample period**
Sub-Saharan Africa	Benin, Cameroon, Congo democratic, Congo Republic, Cote d'Ivoire, Gabon, Ghana, Kenya, Nigeria, Senegal, South Africa, Togo	1980-2011
America	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Honduras, Mexico, Uruguay, Venezuela.	1980-2011
Asia	Bangladesh, China, India, Indonesia, Malaysia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand.	1980-2011
Europe	Austria, Finland, France, Sweden, Turkey.	1980-2011
MENA	Algeria, Egypt, Iran, Jordan, Morocco, Oman, Saudi Arabia, Tunisia.	1980-2011

Table 2 presents some summary statistics of the data. The Table shows one measure of tails i.e. the Skewness among other descriptive statistics. Skewness is a measure of asymmetry of the distribution of the series around its mean. The Skewness of a symmetric distribution is zero. Positive Skewness means that the distribution has a long right tail and negative Skewness implies that the distribution has a long left tail. It is evident from Table 2 that all variables have long tails. A formal test of normality combining the Kurtosis and the Skewness is given by the Jarque-Bera test statistic, which shows that all variables show non-normal distribution. Therefore, estimation technique based on linear Gaussian models will be biased; hence the use of quantile regression estimation is more appropriate.

Table 2: Descriptive statistics

Variables	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Kurtosis**	**Skewness**	**JB**
CO_2 emissions	1440	0.39	1.31	-3.39	3.00	2.36	-0.21	34.60
Energy use	1440	6.75	0.93	4.63	8.98	2.48	0.52	81.30
GDP	1440	7.73	1.31	5.27	10.73	2.43	0.50	79.99
GDP squared	1440	61.54	21.32	27.87	115.28	2.81	0.79	152.42
Industrial sector	1440	3.46	0.31	1.86	4.34	3.90	-0.20	58.24
Finance	1440	3.32	0.86	-0.38	5.24	4.70	-0.79	325.95
Trade	1440	4.06	0.57	1.84	6.08	4.51	0.18	146.10
Urbanization	1440	3.92	0.44	2.69	4.60	2.56	-0.59	96.85

Note: JB refers to the Chi2 statistic from the Jarque-Bera test of normality.

3 Results and discussion

We report in Tables 3 results from quantile regression for the 10th, 25th, 50th, 75th and 90th quantiles. For comparison purposes we also report results of pooled OLS estimates showing the mean effects of all covariates. Figures 1 illustrates how the magnitude of the coefficients of the covariates varies over quantiles.

The OLS results indicate that all the variables except urbanization are significantly related to CO_2 emissions. Energy consumption, the share of the industrial sector and domestic credit to the private sector are detrimental to air quality whereas trade is good for the environment. Further, the results show an inverted U-shaped relationship between CO_2 emissions and GDP, providing support for the EKC hypothesis. On the contrary, urbanization is found to have no significant impact on pollution level. This finding is consistent with that of Sadorsky (2014) but contradicts with that obtained by Sharma (2011).

Table 3: Determinants of CO_2 emissions: OLS versus quantile regression

	OLS	Quantile regression					Test of symmetry[1]		Test of equality[2]
		q10	q25	q50	q75	q90	q10=q90	q25=q75	
Energy use	0.946*	1.135*	1.076*	0.888*	0.899*	0.958*	7.11*	18.16*	6.71*
	(32.42)	(18.15)	(28.82)	(13.61)	(29.63)	(30.46)	(0.007)	(0.000)	(0.000)
Income	2.219*	3.228*	2.419*	1.911*	1.989*	1.223*	41.30*	2.80**	12.37*
	(14.89)	(11.54)	(9.20)	(7.26)	(11.79)	(7.43)	(0.000)	(0.094)	(0.000)

Income squared	-0.129* (-15.13)	-0.191* (-12.18)	-0.146* (-9.65)	-0.111* (-6.69)	-0.115* (-12.57)	-0.076* (-7.81)	42.98* (0.000)	4.67* (0.030)	12.15* (0.000)
Industry	0.470*	0.400*	0.421*	0.573*	0.468*	0.630*	2.96**	0.39	2.56*
	(8.83)	(3.22)	(5.80)	(5.77)	(7.05)	(9.56)	(0.085)	(0.532)	(0.036)
Credit	0.283*	0.285*	0.307*	0.274*	0.214*	0.109*	14.51*	10.87*	9.35*
	(15.47)	(6.74)	(11.02)	(6.98)	(9.52)	(4.44)	(0.000)	(0.001)	(0.000)
Trade	-0.165*	-0.122*	-0.153*	-0.219*	-0.154*	-0.028	2.33	0.00	4.35*
	(-6.82)	(-2.12)	(-4.49)	(-4.22)	(-2.89)	(-0.73)	(0.127)	(0.971)	(0.001)
Urbanization	-0.001	-0.134*	0.043	0.117	-0.021	0.132	5.98*	0.66	4.14*
	(-0.02)	(-2.39)	(0.93)	(1.56)	(-0.27)	(1.38)	(0.014)	(0.416)	(0.002)
Constant	-17.09*	-22.25*	-18.87*	-15.99*	-15.368*	-13.33*	65.71	17.22	17.81
	(-36.81)	(-23.11)	(-21.05)	(-15.64)	(-33.30)	(-21.99)	(0.000)	(0.000)	(0.000)

Note: Asymptotic standard errors are given below each parameter estimate (heteroskedasticity robust for OLS; bootstrapped for quantiles based upon 1000 bootstrapping repetitions). The asterisks ** and * denote significance at the 10% and 5% levels, respectively. (1) F-statistic and associated p-values for symmetry test. (2) F-statistic and associated *p-values* are reported for the test of equality of the coefficients across quantiles (i.e. q10=q25=q50=q75=q90).

The quantile regression results suggest some important differences across different points in the conditional distribution of CO_2 emissions. The impact of energy consumption on CO_2 emissions is positive at all quantiles but larger in magnitude in countries with lower levels of pollution. From Figure 1, we can see that the effect of energy consumption on pollution exhibits an inverted U-shaped relationship with quantiles. For example, a 10% increase in energy consumption increases CO_2 emissions by about 12% in countries at the lower level of pollution but by 9% at the higher level of pollution. The EKC is also confirmed for all quantiles with the positive effect of economic development larger in countries at the left tail of the pollution distribution. Another interesting finding is the impact of the industrial sector. The impact of this variable is positive and larger at the top tail of the distribution, suggesting that industrialization increases pollution especially in countries with higher level of pollution. Financial deepening measured as bank credit to private sector contributes to increase CO_2 emissions and its impact is larger in countries with lower levels of pollution.

With respect to trade, the effect is negative and shows a U-shaped relation with quantiles, suggesting that openness to trade reduces pollution with larger reducing-effect in countries in the middle part of the pollution distribution. The impact of trade is not significant at the top tail of the pollution distribution (i.e. 0.80 quantile and higher). The impact of urbanization which was found to be insignificant in the OLS regression is significant and negative for lower quantiles (0.10 and lower). This suggests that urbanization lowers pollution only in low pollution countries. For the 0.15 quantile and higher, the effect of urbanization on pollution is not significant. This finding shows that the effects of urbanization on the environment are not necessarily linear and symmetric. Bigger urban areas do not always create more environmental damages and small urban areas can cause large environmental problems. The extent of the environmental impacts of urbanization depends upon how the urban populations behave their consumption and living patterns not just how large they are.

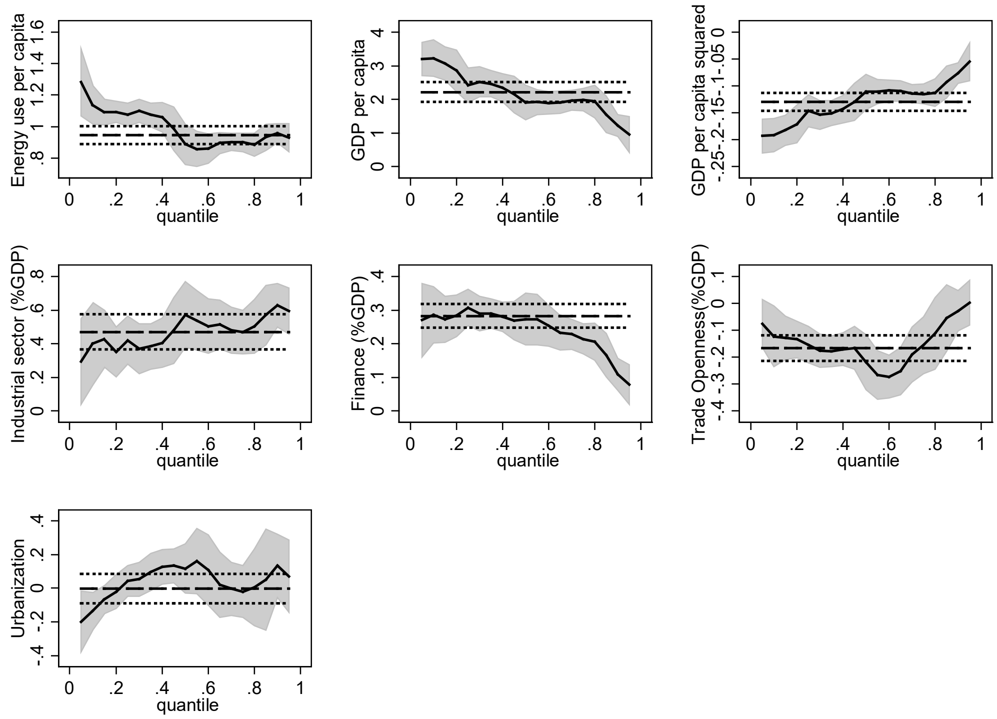

Figure 1: The parameter estimates of quantile and OLS regressions and their confidence intervals.
Note: The x-axis represents the conditional quantile of CO_2 emissions. The horizontal dashed line represents the OLS estimates. The two dotted lines depict the 95 percent confidence intervals for the OLS estimates. The solid line represents the quantile regression estimates; and the shaded grey area plots the 95 percent confidence band for the quantile regression estimates.

4 Conclusion

This paper examines the determinants of CO_2 emissions in a panel of 45 countries. Previous studies on this issue focused on the mean effects by using mean regression framework. In this study, however, we use quantile regression technique to analyze whether or not factors that affect pollution do so in the same way for low and high pollution countries. The baseline OLS regression results indicate that energy consumption, economic development, industrialization, financial development and trade openness are the major drivers of CO_2 emissions. The quantile regression estimates support some findings in the literature, while others reveal sensitivity to the pollution level. For example, energy consumption consistently increases pollution and its impact is larger in magnitude in low pollution countries. This suggests that energy conservation policies in low pollution economies may be more beneficial to the environment. Further, the EKC is also confirmed for all quantiles, the positive effect of economic development being larger in low pollution countries. Industrialization also increases pollution especially in countries with higher level of pollution. The effect of bank credit to private sector is positive and larger in countries with lower levels of pollution. This suggests that financial sector development in low pollution countries will increase pollution level through the increase in the demand of energy-consuming technologies. Openness to trade reduces pollution in countries that are not at the top tail of the pollution distribution, the reducing effect being larger in the middle part of the distribution. This finding implies that international trade may help to reduce pollution in low pollution countries. Urbanization lowers pollution only in low pollution countries.

The findings of this study show that pollution control policies are unlikely to succeed equally across countries with different levels of pollution. To be effective, pollution control policies should be tailored differently across the low and high pollution countries, especially with respect to the role of economic development, trade and urbanization. More precisely, low- pollution countries should open up their economies to international trade and adopt energy conservation policies as well as enhance urbanization. High-pollution countries should seek balance between industrialization and environmental pollution regulation to achieve sustainable development. In these countries, efforts should be done to develop improved technology that enables higher economic growth with less pollution.

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