The Impact of Urbanization on CO_2 Emissions: Evidence from Developing Countries

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Abstract

This paper analyzes the impact of urbanization on CO_2 emissions in developing countries, taking into account the presence of heterogeneity in the sample of countries and testing for the stability of the estimated elasticities over time. The sample covers the period from 1975 through 2003 for different groups of countries, classified according to their income levels. Our results show that, whereas the impact of population growth on emissions is above unity and only slightly different for upper, middle, and low- income countries, urbanization, demonstrate a very different impact on emissions for low and lower-middle-income countries and upper-middle income countries.

JEL Code: Q25, Q4, Q54.

Keywords: CO_2 emissions, developing countries, panel data, population growth, urbanization.

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Abbreviations: IPAT, STIRPAT, EKC, WDI, GDP, IND, EI, FGLS, PPP

THE IMPACT OF URBANIZATION ON CO_2 EMISSIONS: EVIDENCE FROM DEVELOPING COUNTRIES

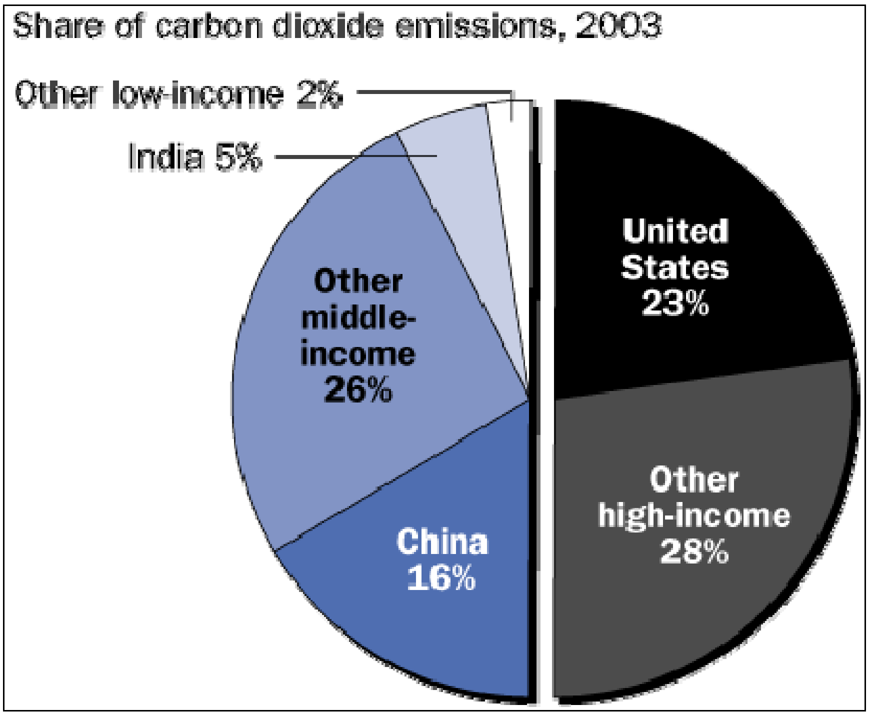
1. Introduction

Climate change, with the attendant need to stabilize contributing global emissions, is one of the most challenging problems of our times and a matter of great concern among policy makers. Some aspects of the projected impact, such as global warming, increasing desertification, rising sea levels and rising average temperatures, might have a disproportionate impact on developing countries, which least contributed to the cause of climate change.

While many factors have been adduced for climate change, energy consumption, as affluence grows, is singled out as having the most adverse impact on the environment. However, this impact is more severe when accompanied by demographic growth, given that population increases lead to increases in energy consumption and, consequently, to greater atmospheric pollution. A number of factors, namely, the increase in life expectancy, reduced child mortality, and improved farming methods, have resulted in rapid and exponential growth of world population over the last 150 years. World population is currently growing by approximately 1.5 percent, or 80 to 85 million per year. But this trend will not continue indefinitely. The latest UN world population projections to 2150 suggest that a slowing down of population growth may already be occurring with a median projection of 9.4 billion by 2050. The population growth is expected to be concentrated in the developing regions of the world, mainly Africa and Asia, while in the developed countries, growth will be very slow.

The main greenhouse gas in terms of quantity is CO_2, which, according to IPCC (2007), accounts for about 76.7 percent of total anthropogenic greenhouse gas emissions in 2004. Although the reduction commitments of CO_2 emissions were seen as a task predominantly for developed countries (UNFCCC, 1997), based on the consensus that they are the largest contributors to global CO_2 emissions, there have been recent calls for the developing countries to play an active role in global emissions reduction (Winkler et al., 2002). The level of CO_2 emissions from developing countries has been rapidly exceeding that of the developed countries, and at present accounts for almost 50 percent of the world's CO_2 emissions (Figure 1). This trend is expected to grow if the current path, in terms of energy consumption, is maintained.

Figure 1. Carbon dioxide emissions in 2003



Source: World Development Indicators 2007

Since CO_2 is one of the main contributors to global emissions, it is of great interest to determine which policy measures will be more effective in curbing CO_2 emissions.

In the last two decades, a number of researchers have investigated the determinants of CO_2 emissions within the framework of the Kuznets Curve hypothesis without reaching conclusive evidence in favor of the hypothesis (See Perman and Stern, 2003, for a survey). More recent developments use decomposition analysis and efficient frontier methods, taking into account not only affluence, but also energy intensity, technical change, and structural change as explanatory variables. In most cases changes in per-capita CO_2 emissions are explained with changes in income per capita, energy intensity, and structural change in the economy, assuming implicitly that population has a unitary elasticity with respect to emissions. Relatively little effort has been devoted to investigating the impact of demographic factors on the evolution of CO_2 emissions and most of the existing studies assume that this impact is comparable for all countries and constant over time (Cole and Newmayer, 2004). Two exceptions to this general assumption are the studies of Shi (2001), who grouped countries according to income levels, and Martínez-Zarzoso et al. (2007), who studied the impact of population growth for old and new European Union members.

The primary objective of this research is to investigate the differential impact of demographic factors on CO_2 emissions by using an econometric model to decompose emissions data into the scale, composition, and technique effects. The study focuses on different groups of developing countries, and considers the heterogeneity present in the sample in terms of variability of the estimated coefficients over time and across different groups of countries. We specify a model in which CO_2 emissions are related to the level of income per capita, the population size, the percent of urban versus rural population, the industrial structure, and the energy intensity of each country. The study involves three groups of countries classified by the World Bank as upper, middle, and low-income countries and analyzes the behavior of each group separately. The results show important disparities among groups. For low-income countries the elasticity emission-urbanization is higher than unity, whereas for lower-middle-income the elasticity is 0.72, which is in accordance with the higher environmental impact observed in less developed regions. However, in upper and highly developed countries, the elasticity, emission-urbanization, is negative.

The paper is organized as follows. Section 2 briefly reviews the relevant literature. Section 3 presents the theoretical framework and specifies the model. Section 4 describes the empirical analysis and discusses the main results and Section 5 concludes.

2. Literature Review

The first studies that considered demographic factors to explain the sources of air pollution were based on cross-sectional data for only one time period. In this line, Cramer (1998, 2002) and Cramer and Cheney (2000) evaluated the effects of population growth on air pollution in California and found a positive relationship only for some sources of emissions but not for others. Dietz and Rosa (1997) and York, Rosa, and Dietz (2003) studied the impact of population on carbon dioxide emissions and energy use within the framework of the IPAT[1] model. The results from these studies indicate that the elasticity of CO_2 emissions and energy use with respect to population are close to unity. The unity assumption for the population elasticity is embedded in the original IPAT formulation of Ehrlich and Holdren (1971) but not in the stochastic version of the IPAT (STIRPAT) formulated by Dietz and Rosa (1997).

In a panel data context, Shi (2003) found a direct relationship between population changes and carbon dioxide emissions in 93 countries over the period from 1975 to 1996. He found that the impact of population on emissions varies with the levels of affluence and has been more pronounced in lower-income countries than in higher-income countries. Also using panel data, Cole and Neumayer (2004) considered 86 countries during the period from 1975 to 1998 and found a positive link between CO_2 emissions and a set of explanatory variables

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[1] Impact=Population .Affluence.Technology (IPAT).

including population, urbanization rate, energy intensity, and smaller household sizes. However, the authors assumed that the effect of population and urbanization is equal for all income levels. Previous research also outlined the negative environmental impact caused by demographic pressure (Daily and Ehrlich, 1992; Zaba and Clarke, 1994), but they failed to analyze this impact within an appropriate quantitative framework.

In addition, several studies have discussed and tested the existence of an Environmental Kuznets Curve (EKC) where the relationship between pollution and income is considered to have an inverted U-shape. These models frequently take emissions per capita for different pollutants as an endogenous variable, assuming implicitly that the elasticity, emission-population, is unitary. A few of them considered population density as an additional explanatory variable (e.g., Cole et al., 1997; Panayotou et al., 2000). However, their tests are not based on an underlying theory, and testing variables individually is subject to the problem of omitted-variables bias. The results obtained within this framework are far from homogeneous and their validity has been questioned in recent surveys of the EKC literature (e.g., Stern, 1998 and 2004). Most of the criticisms are related to the use of inappropriate techniques and the presence of omitted-variables bias. In fact, Perman and Stern (2003) state that when diagnostic statistics and specification tests are taken into account and the proper techniques are used, the results indicate that the EKC does not exist. Borghesi and Vercelli (2003) consider that the studies based on local emissions present acceptable results, whereas those concerning global emissions do not offer the expected outcomes, and therefore the EKC hypothesis cannot be generally accepted.

There are two new approaches that go beyond the EKC literature. They are based on decomposition analysis and are known as *index number decompositions* and *efficient frontier methods*. The first approach requires detailed sectoral data and does not allow for stochasticity, whereas the second (frontier models) is based on the estimation of econometric models, allows for random errors, and estimates factors common to all countries.

Decomposition methods have been applied to an increasing number of pollutants in developed and developing countries (e.g., Hamilton and Turton, 2002; Bruvoll and Medin, 2003; Lise, 2005). Emissions are typically decomposed into scale, composition, and technique effects. Scale effects are measured with income and population variables, composition effects refer to changes in the input or output mix, and technique effects are proxied by energy intensity (the effect of productivity on emissions) and global technical progress. Hamilton and Turton (2002) concluded that income per capita and population growth are the two main factors increasing carbon emissions in OECD countries, whereas the decrease in energy intensity is the main factor reducing them. Bruvoll and Medin (2003) covered 10 pollutants and determined that in all cases, technique effects were dominant in offsetting the increase in scale. The authors concluded that, whereas structural change explains the increase in energy intensity during the period from 1913 through 1970, technical change is the main factor reducing energy intensity after 1970. Shifts in the fuel mix are the main factor explaining carbon emissions per unit of energy used. Stern (2002) used an econometric model to decompose sulphur emissions in 64 countries during the period 1973 to 1990 and found that the contribution of input and output effects on changes in global emissions is very modest, whereas technological change considerably reduces the increase in emissions.

3. Basic Framework of Analysis

Erlich and Holdren (1971) suggested a suitable framework for analyzing the determinants of environmental impact known as the equation, IPAT: $I=PAT$ where I represents environmental impact, P is the population size, A is the level of population affluence, and T denotes the level of environmentally damaging technology. The impact of human activity in the environment is viewed as the product of these three factors. Initially, this formulation was purely conceptual and could not be used directly to test hypotheses on the impact of each one of the above-mentioned factors on emissions.

The IPAT model can be expressed as an identity where *A* could be defined as consumption per capita and *T* as pollution per unit of consumption. As stated by MacKellar et al. (1995), the IPAT identity is a suggestive approach that shows how environmental impact is not due to a single factor. However, these authors outline the limitations of testing this identity related to the choice of variables and the interactions between them. They compare households (*H*) with total population levels, as the demographic unit used to forecast future world CO_2 emissions, and they show how each choice leads to different predictions in all the regions of the world, always increasing the impact on emissions for the *I=HAT* model, where the term, households, replaces the term, population.

Cole and Neumayer (2004) refer to the utility of the tautological version of the IPAT model for decomposition purposes but also highlight its limitations in estimating population elasticities. For such estimation they used the model proposed by Dietz and Rosa (1997). Starting from Ehrlich and Holdren's (1971) basic foundation, Dietz and Rosa (1997) formulated a stochastic version of the IPAT equation with quantitative variables containing population size (*P*), affluence per capita (*A*), and the weight of industry in economic activity as a proxy for the level of environmentally damaging technology (*T*). These authors designated their model with the term, STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology). The initial specification is given by the following equation:

$$I_i = \alpha P_i^{\beta} A_i^{\gamma} T_i^{\delta} e_{i,} \qquad [1]$$

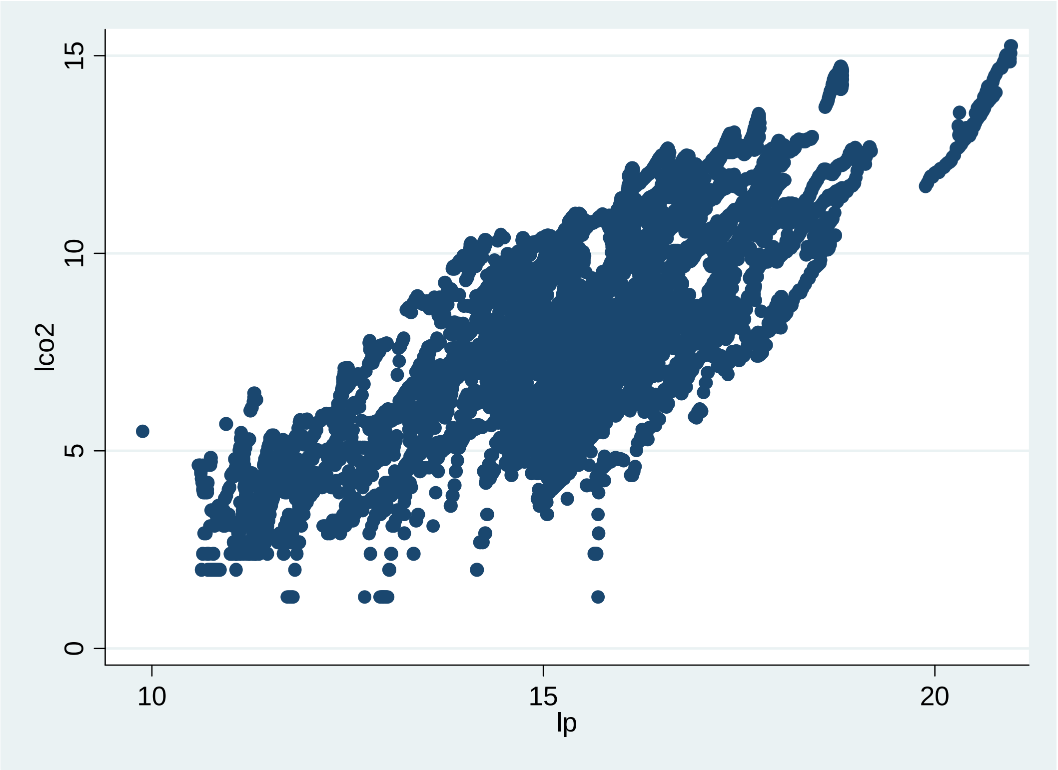
where I_i, P_i, A_i, and T_i are the variables defined above; α, β, γ, and δ are parameters to be estimated, and e_i is the random error. Their results corroborated the Malthusian thesis in the sense that population growth has a greater-than-proportional impact on CO_2 emissions. On the other hand, the study conducted by Cramer (1998), based on a similar model, showed a contamination-population elasticity less than unity for the five pollutants analyzed in several areas of the USA. This discrepancy could be explained by the exclusion of carbon dioxide among the pollutants considered by this author.

Similar to Cole and Neumayer (2004), we have also taken the STIRPAT model as the reference theoretical and analytical framework. P is measured with total population and with the percentage of urban population. The affluence variable, *A,* is measured by the gross domestic product per capita and, as a proxy for measuring *T,* we have considered the percentage of industrial activity with respect to total production and energy efficiency. Our empirical analysis is also in line with the latest emerging approaches based on decomposition methods described in the introduction. We think that the factors driving changes in pollution should be analyzed in a single model and under the appropriate quantitative framework, hence allowing for a more flexible model with variable coefficients across groups with different behavior and over time.

4. Econometric estimation

Following the empirical model formulated by Dietz and Rosa (1997), I have estimated a linear version of the STIRPAT model for a sample of 95 countries during the period from 1975 to 2003. The countries under analysis are classified into three income groups according to data from the World Development Indicators (WDI) 2007. Low-income economies are those in which 2005 GNI per capita was $875 US or less (54 countries). Lower-middle-income economies are those in which 2005 GNI per capita was between $876 and $3,466 (58 countries), upper-middle-income economies are those in which 2005 GNI per capita was between $3,466 and $10,725 (40 countries). The sample of countries is considerably reduced when energy efficiency is included as an explanatory variable since data for this variable are not available for many developing countries[2]. There are also some countries for which income data are missing and transition economies only report data since the early 1990s, when their economies began the opening-up process. Countries considered in each group are listed in Table A.7 in the appendix (WDI, World Bank, 2007). A summary of the data for each group of countries, as well as the simple correlation coefficients between the variables in the model, is shown in Tables A1 to A3 in the appendix. In addition, Figures 2 and 3 report two scatter plots.

Figure 2. Scatter plot: CO_2 and population



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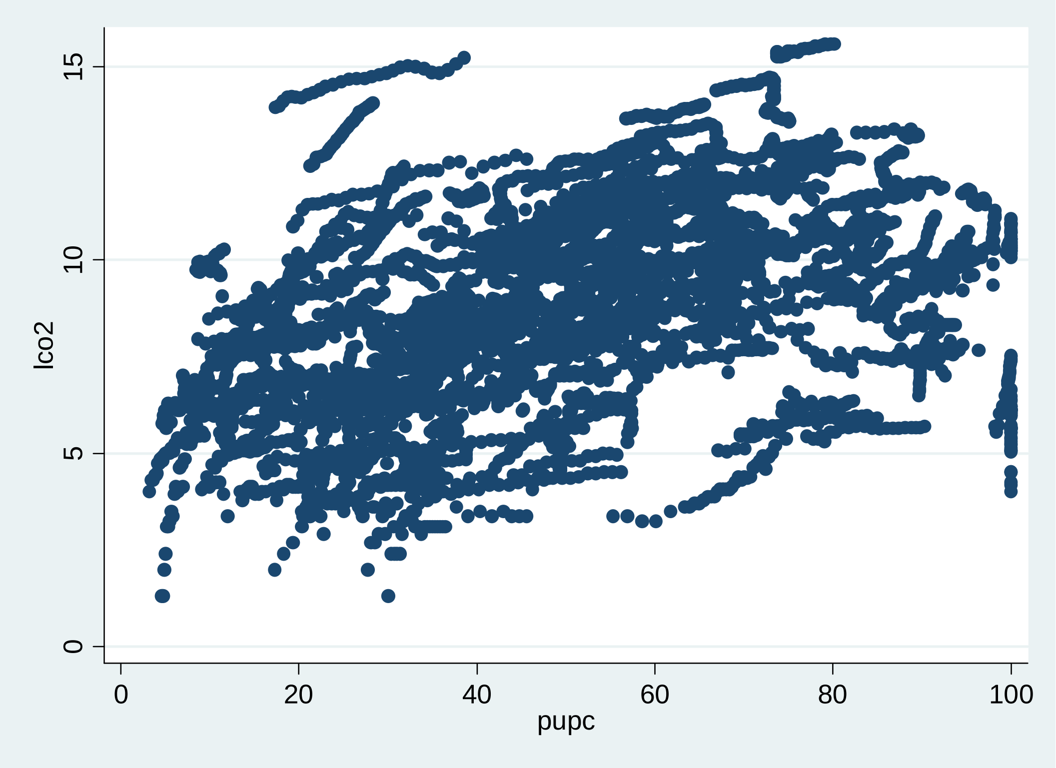
[2] Energy Efficiency is available for 31 Low-income countries, 38 Lower-middle-income countries, 26 upper-middle-income countries and 35.

Figure 3. Scatter plot: CO_2 and urbanization



Note: *lp denotes population in natural logs, pupc is the percentage of urban population over total population and lco2 denotes logged CO_2 emissions.*

The first one shows a clear positive linear relationship between population and emissions, whereas the second shows a positive relationship between urbanization and emissions for low urbanization levels and a negative one for higher levels (more than 60 percent of urban population). We proceed now with a more sophisticated analysis to investigate this relationship in depth.

In order to test whether the evolution of the factors considered in the STIRPAT model influences the level of CO_2 emissions through time and across countries, I have derived the empirical model by taking logarithms of Equation 1 as follows:,

$$\ln I_{it} = \alpha_i + \beta \ln P_{it} + \gamma \ln A_{it} + \delta_i \ln T_{it} + \phi_t + e_{it,} \qquad [2]$$

where the sub-index *i* refers to countries and *t* refers to the different years. I_{it} is the amount of CO_2 emissions in tons, P_{it} is the population, A_{it} is the Gross Domestic Product (GDP) per capita expressed in constant PPP (purchasing parity prices) (2000 US$), and T_{it} is proxied with two variables: the percentage of the industrial activity with respect to the total production measured by the GDP (IND) and energy efficiency (EI) measured as GDP at constant PPP prices divided by energy use, where *energy use* refers to apparent consumption (production+imports-exports). Finally, δ_i and ϕ_t capture the country and time effects, respectively, of each country, and e_{it} is the error term. Since the model is specified in natural logarithms, the coefficients of the explanatory variables can be directly interpreted as elasticities. The time effects, $\phi_{t,}$ can be considered as a proxy for all the variables that are common across countries but which vary over time. Within the context of decomposition analysis, these effects are sometimes interpreted as the effects of emissions-specific technical progress over time (Stern, 2002).

Equation 2 was first estimated for the whole set of countries under analysis (an unbalanced panel with 1971 observations). Table 1 shows the results obtained by using different estimation methods. The model was first estimated using random effects (Model 1) and fixed effects (Model 2). Since the country and time-specific effects are statistically significant (as indicated by the respective LM tests) the OLS results with a common intercept are not reported. The result of the Hausman test indicates that the country effects are correlated with the residuals and therefore only the fixed-effects estimates are consistent. Since the time dimension of the panel is relatively large (31 years), serial correlation is almost certainly present in our data. I confirm this hypothesis by performing the Wooldridge autocorrelation test for panel data. In order to get consistent estimates, feasible generalized least squares (FGLS) techniques can be used. A second problem to be accounted for is the presence of heteroskedasticity, as indicated by the result of the LR test reported in the last row of Table 1.

Table 1. Regression results for all countries in the sample (1975-2003)

Method:	**RE**	**FE**	**FE AR(1)**	**GLS ARC**	**GLS HET**	**GLS HET ARC**	**GLS HET ARSP**
Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Variables	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
lyh	2.503***	2.188***	1.233***	1.521***	1.493***	1.358***	1.418***
	(11.73)	(9.84)	(16.11)	(71.57)	(143.86)	(56.23)	(62.69)
lp	1.012***	1.123***	1.174	1.053***	1.068***	1.057***	1.069***
	(31.18)	(9.37)	(1.04)	(119.16)	(244.29)	(102.14)	(91.48)
pupc	-0.106	-1.129***	-0.257	0.523***	0.321***	0.486***	0.677***
	(-0.582)	(-4.58)	(-0.47)	(5.64)	(7.27)	(4.77)	(6.62)
lei1	-0.899***	-0.788***	-0.786***	-0.968***	-1.012***	-1.013***	-1.091***
	(-22.64)	(-16.53)	(-12.03)	(-39.09)	(-84.15)	(-44.46)	(-54.68)
lia	0.313***	0.288***	0.144***	0.688***	0.561***	0.146***	0.170***
	(7.81)	(6.84)	(3.44)	(17.24)	(22.68)	(5.45)	(7.01)
cons	-8.849***	-10.64***	0.790***	-6.812***	-5.849***	-3.377***	-3.128***
	(-9.68)	(-5.01)	(-9.95)	(-17.75)	(-28.05)	(-8.67)	(-8.65)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lm test	4565	Prob=0.00					
Hausman test	548	Prob= 0.00					
N	1971	1971	1883	1971	1971	1971	1971
Adjusted R^2		0.588	0.487				
RMSE	0.278	0.274	0.16				
Log Likl.		-179	791.6	-1616.3	-752.8	1591.4	1864.5
Wooldridge test for autocorrelation				F(1.87)=33.18			
LR test for Heteroskedasticity				Chi(87)=2542			

*Note: lyh denotes per- capita income, lp denotes population, pupc is the percentage of urban population over total population, lei1 is energy efficiency, and lia is the percentage of industrial activity over total GDP. t-statistics are in brackets. *, **, *** denote significance at the 10, 5, and 1% level, respectively.*

In order to deal with both problems simultaneously, autocorrelation and heteroskedasticity in the error term, the model is estimated using FGLS assuming heteroskedasticity and panel-specific AR1 correlation (Model 7). To see the effects on the estimated parameters of each problem separately, Models 4 and 5 assume respectively autocorrelation[3] and heteroskedasticity and Model 6 assumes heteroskedasticity and panel-common AR1. The model that shows a higher log-likelihood is Model 7 and this is going to be utilized to estimate regressions for different income groups.

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[3] We also estimated the model taking first differences of the series as an alternative to account for autocorrelation, and the results were similar.

The results indicate that all of the variables included are statistically significant and show the expected signs. With respect to the estimated elasticities, the population elasticity is slightly higher than one, in line with previous research, and the percentage of urban population also has a positive effect on CO_2 emissions. The estimated coefficient for income per capita indicates a higher-than-proportional effect on emissions, and an increase in energy efficiency decreases emissions proportionally. Finally, the effect of the percentage of industrial activity is positive and small, and the time effects show a negative sign and an increasing magnitude over time; this could be indicative of global technical progress over time that is reducing emissions.

Since the time span is large, another matter of concern is the stationarity of the series. If the series are non-stationary, the results could be showing spurious relationships. Although this problem is greatly reduced with the use of panel data, I consider two possible ways of approaching this issue. The first is to test for unit roots using panel unit root tests and if all the series are non-stationary and integrated of order one, to then search for a long-run equilibrium relationship. The second approach is to estimate the model for a cross-section of countries in each year and see whether the results hold. Since I also wanted to explore the changing role of affluence, increasing population, urbanization, and industrialization along countries' development paths, the second approach is followed. The yearly regressions are also estimated using feasible generalized least squares, since heteroskedasticity is present in the data. The results are reported in Table 2.

The estimated coefficients indicate that population size contributes to emissions at an almost constant rate, whereas income per capita contributes to emissions at an increasing rate over the whole period. Industrialization contributes to CO_2 emissions but at a decreasing rate as income increases and energy efficiency make negative contributions to emissions at a slightly decreasing rate. It is worth noting the fall in the contribution of urbanization over time and the change from a positive to a negative contribution in the Eighties.

Table 2. Feasible generalized least squares estimation results for all countries with population weights (various years)

Year	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2003**
Variables	**Coeff.**	**Coeff.**	**Coeff.**	**Coeff.**	**Coeff.**	**Coeff.**	**Coeff.**
lyh	1.032***	1.339***	1.481***	1.637***	1.764***	1.794***	1.810***
	(3.47)	(6.34)	(6.74)	(7.97)	(7.49)	(13.23)	(13.92)
lp	1.072***	1.138***	1.162***	1.194***	1.082***	1.050***	1.053***
	(24.18)	(23.97)	(28.42)	(25.26)	(23.65)	(22.71)	(26.42)
pupc	0.722	0.0190	-0.576	-0.639	-1.088	-1.083**	-1.201**
	(0.70)	(0.02)	(-0.55)	(-0.66)	(-1.30)	(-2.06)	(-2.17)
lia	0.975***	0.731***	0.944**	0.775**	0.650**	0.260	0.193
	(4.17)	(3.37)	(3.21)	(2.56)	(1.99)	(1.04)	(1.08)
lei1	-0.952***	-1.056***	-1.052***	-0.916***	-0.919***	-0.869***	-0.834***
	(-4.10)	(-6.07)	(-5.98)	(-5.16)	(-6.63)	(-7.93)	(-7.99)
Constant	-5.310*	-6.144**	-8.301***	-11.620***	-9.942***	-9.187***	-9.718***
	(-1.95)	(-2.08)	(-2.99)	(-3.98)	(-3.80)	(-4.36)	(-5.01)
Observations	46	51	59	67	87	88	87
Adjusted R^2	0.969	0.972	0.968	0.968	0.970	0.971	0.976

*Note: lyh denotes per- capita income, lp denotes population, pupc is the percentage of urban population over total population, lei1 is energy efficiency, and lia is the percentage of industrial activity over total GDP. t-statistics are in brackets. *, **, *** denote significance at the 10, 5, and 1% level, respectively.*

That lends support to the existence of structural change. To explore further the apparently changing role of the variables explaining emissions, I divided our panel data into three groups of countries: low, lower-middle, and upper-middle income. Table 3 shows the results.

The main differences between the three sets of results concern urbanization. The elasticity emissions-urbanization, is negative and significant for the upper-middle-income group, whereas for lower-middle and low-income countries, it is positive and significant. It is much higher than unity (2.82) for low-income countries and it has a less-than-proportional effect for lower-middle-income countries. The inclusion of urbanization in the model does not change the estimated coefficients of the other explanatory variables. The model was also estimated without this variable and the only difference was that the Log-Likelihood was lower in magnitude.

Table 3. Estimation results for each income group (1975-2003)

Model	**GLS with HET and AR(1) Specific terms**		
Variables	**Up-Mid**	**L-Mid**	**Low**
lyh	1.118***	1.316***	1.883***
	(30.76)	(30.49)	(24.6)
lp	1.016***	1.106***	1.207***
	(64.3)	(58.07)	(49.17)
pupc	-0.246**	0.729***	2.828***
	(-2.53)	(3.81)	(5.67)
lei1	-1.013***	-1.137***	-1.206***
	(-27.97)	(-35.09)	(-17.02)
lia	0.122***	0.145***	0.126**
	(2.86)	(3.75)	(2.51)
cons	-0.232	-2.437***	-7.282***
	(-0.35)	(-4.95)	(-7.80)
Time dummies	Yes	Yes	Yes
N countries	25	39	24
Log. Likl	714.9	804.1	387.7

*Note: t-statistics are in brackets. *, **, *** denote significance at the 10, 5, and 1% level, respectively. Note: lyh denotes per-capita income, lp denotes population, pupc is the percentage of urban population over total population, lei1 is energy efficiency, and lia is the percentage of industrial activity over total GDP.*

The results are also confirmed when I examine the evolution over time of the emissions-urbanization elasticity. I obtained a positive and decreasing elasticity for low-income countries and a negative and increasing elasticity for upper-middle-income countries (See Tables A.4 to A.6 in the appendix[4].

Concerning population, higher emissions-population elasticity is obtained for low and lower-middle-income countries (1.21 and 1.11, respectively) than for upper-middle-income countries (1.016). The elasticity for high-income countries (not reported, available upon request) was very similar to the one obtained for the upper-middle group (1.014). A great number of studies confirm an overall upward trend in global emissions over the last decades that share two characteristics. First, emissions have grown faster than population, and second, this relationship is more pronounced for developing countries than for developed countries.

Similar to other studies, I find that for developed countries, the emissions-population elasticity presents a lower coefficient. Shi (2003) calculated an elasticity of 1.58 for

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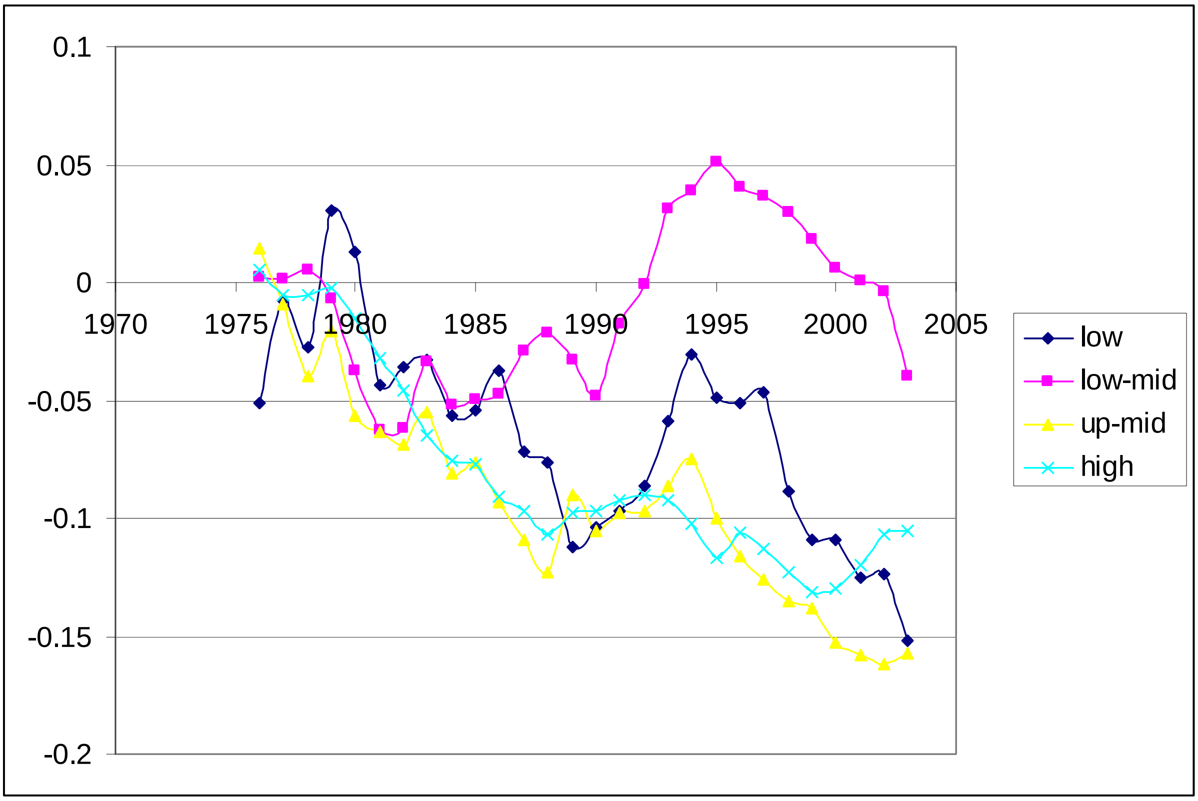
[4] Equation 3 was estimated without energy efficiency because data for this variable were not available for a number of countries as indicated in A.7.

developing countries and 0.83 for developed ones. Also, MacKellar et al. (1995) found that population growth had more influence regarding energy consumption in less developed regions (2.2 in developing and 0.7 in developed regions). This disparity holds also when considering households instead of individuals.

Figure 4 presents the time effects of four groups of countries. I observe an overall decreasing trend in the magnitude of the estimated coefficients for upper-middle-income and high-income countries over the whole period. However, for low and lower-middle-income countries, this decreasing trend is only observed in the 1980s and from 1995 to 2003. In fact, since 1995 this decreasing trend is much more pronounced for these two groups of countries.

Figure 4. Time effects for different income-groups



Note: Estimates based on the results shown in Table 3.

Assuming that these effects can represent specific technical progress over time, the results indicate that technical progress has contributed to the decrease in CO_2 emissions, especially in developing countries in the latest years of the sample.

Some differences have also been observed in the other explanatory variables. An increase of 1 percent in the GDP per head causes a 1.17 percent increase in CO_2 emissions of upper-middle-income countries and a 1.88 percent low-income countries. The negative contribution of energy efficiency to emissions is also different: in the first group, the impact is also lower than that obtained for the second (the elasticities are -1.01 and -1.20, respectively). To sum up, the environmental impact caused by population, urbanization, and affluence variables (scale effect) seems to be higher in low-income countries, whereas the contribution of the industrial sector to emissions is similar for all countries.

5. Conclusions

In this paper a multivariate analysis of the determinants of carbon dioxide emissions in developing countries during the period 1975 to 2003 has been conducted. I have taken the Dietz and Rosa (1997) formulation as our theoretical framework. In their model, population is introduced as a predictor, together with affluence per capita and the level of environmentally damaging technology, proxied with the weight of the industrial sector in the GDP and with energy intensity. Affluence was measured by the GDP per capita in PPP. I have added urbanization as a predictor and used several estimation methods in a panel data framework.

The results show different patterns for low-income and lower-middle-income countries and the rest. For the first set of countries, the elasticity emission-urbanization is higher than unity, whereas in the second group, the elasticity is 0.72, which is in accordance with the higher environmental impact observed in less developed regions. However, in upper and highly developed countries, the elasticity, emission-urbanization, is negative.

This result has a very important policy implication: once urbanization reaches a certain level, the effect on emissions turn out to be negative, contributing to reduced environmental damage. This result is also confirmed when I observe the evolution over time of the emissions-urbanization elasticity. I obtained a positive and decreasing elasticity for low-income countries and a negative and increasing elasticity for upper-middle-income countries.

In 2008 more than half of the world's human population (3.3 billion people) is living in urban areas. By 2030, this is expected to increase to almost 5 billion. Although many of these cities will be poor, no country in the industrial age has ever achieved significant economic growth without urbanization. Cities may concentrate poverty, but they also represent the best hope of escaping it. Although cities embody the environmental damage, namely, increasing emissions due to transportation, energy consumption and other factors, policymakers and experts increasingly recognize the potential value of cities to long-term sustainability. It could be that these potential benefits of urbanization outweigh the disadvantages. This is the main message of this paper.

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Appendix

A1. Summary statistics and correlations for low-income countries

Least Developed countries

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
lco2	1512	7.468	2.116	1.298	14.057
Lyh	1292	6.855	0.498	5.393	8.147
Lp	1653	15.869	1.576	11.316	20.814
Pupc	1653	0.260	0.125	0.032	0.616
lei1	621	14.689	0.641	13.147	16.276
Lia	1307	2.994	0.404	0.632	4.072

Correlations	lco2	lyh	lp	pupc	lei1	lia
lco2	1.000					
Lyh	0.347	1.000				
Lp	0.794	0.076	1.000			
Pupc	0.107	0.441	-0.234	1.000		
lei1	0.026	0.634	0.136	0.104	1.000	
Lia	0.435	0.244	0.140	0.336	-0.146	1.000

A2. Summary statistics and correlations for lower-middle-income countries

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
lco2	2330	8.694	2.528	1.298	15.237
Lyh	1401	7.931	0.580	5.435	9.109
Lp	2632	15.168	2.086	9.616	20.989
Pupc	2632	0.433	0.170	0.034	0.861
lei1	986	15.109	0.582	12.981	16.315
Lia	1653	3.365	0.409	0.929	4.435

Correlations	lco2	lyh	lp	pupc	lei1	lia
lco2	1					
Lyh	0.2535	1				
Lp	0.8526	-0.001	1			
Pupc	0.1067	0.543	-0.173	1		
lei1	-0.173	0.509	0.004	0.118	1	
Lia	0.42	-0.001	0.311	0.062	-0.257	1

A3. Summary statistics and correlations for upper-middle-income countries

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
lco2	1590	8.655	3.012	1.991	14.719
Lyh	916	8.586	0.605	6.538	9.930
Lp	1668	14.611	2.182	9.888	18.817
Pupc	1656	0.5278	0.196	0.031	0.934
lei1	602	15.071	0.520	13.937	16.211
Lia	1075	3.454	0.414	2.043	4.4878

Correlations	lco2	lyh	lp	pupc	lei1	lia
lco2	1					
Lyh	0.2419	1				
Lp	0.8961	0.0407	1			
Pupc	0.2124	0.2426	0.309	1		
lei1	-0.3570	0.2246	-0.0741	0.3082	1	
Lia	0.0200	0.009	-0.1720	-0.1527	-0.3687	1

Table A.4. Generalized least squares estimation results with population weights (various years/ low-income countries)

YEAR	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2003**
lyh	-0.388	-0.202	-0.133	1.156***	1.402***	1.468***	1.444***
	(-0.40)	(-0.20)	(-0.29)	-3.89	-3.9	-5.24	-4.69
lp	1.159***	1.188***	1.229***	1.159***	1.145***	1.149***	1.148***
	(19.7)	(22.66)	(13.76)	(15.68)	(17.14)	(16.55)	(14.29)
pupc	6.277*	6.689**	7.747***	4.596**	3.983**	3.198**	3.526**
	(1.89)	(2.50)	(5.15)	(3.12)	(2.52)	(2.11)	(2.63)
lia	0.780	0.934**	1.158**	1.011***	0.670*	0.496	0.207
	(1.14)	(2.19)	(2.22)	(2.97)	(1.81)	(1.44)	(0.54)
Constant	-12.42**	-14.69**	-16.84***	-23.29***	-23.78***	-23.81***	-22.96***
	(-2.11)	(-2.30)	(-6.87)	(-16.43)	(-13.38)	(-15.65)	(-14.93)
Observations	27	30	35	41	44	46	46
Adjusted R^2	0.953	0.963	0.972	0.964	0.963	0.959	0.956

Note: lyh denotes per-capita income, lp denotes population, pupc is the percentage of urban population over total population and lia is the percentage of industrial activity over total GDP.
*t-statistics are in brackets. *, **, *** denote significance at the 10, 5, and 1% level, respectively.*

Table A.5. Generalized least squares estimation results with population weights (various years/ lower-middle-income countries)

	1975	**1980**	**1985**	**1990**	**1995**	**2000**	**2003**
lyh	-0.323	-0.209	-0.067	0.667	0.325	1.159***	0.921**
	(-0.99)	(-0.49)	(-0.12)	(1.41)	(1.15)	(4.14)	(2.27)
lp	0.882***	1.046***	1.139***	1.145***	0.988***	0.926***	0.861***
	(7.78)	(7.46)	(8.52)	(9.34)	(11.42)	(23.19)	(11.55)
pupc	2.495*	2.195	1.055	-0.227	0.280	-0.028	-0.993
	(1.75)	(1.26)	(0.65)	(-0.15)	(0.28)	(-0.04)	(-1.02)
lia	2.549***	1.072	0.532	1.500	1.728**	1.610***	1.137***
	(3.70)	(1.13)	(0.56)	(1.48)	(2.39)	(4.01)	(3.16)
Constant	-12.70***	-10.84**	-11.05**	-19.62***	-15.05***	-20.34***	-32.58***
	(-5.92)	(-2.89)	(-2.41)	(-3.66)	(-5.30)	(-9.94)	(-5.05)
Observations	26	30	33	44	49	49	47
Adjusted R^2	0.980	0.958	0.947	0.913	0.941	0.963	0.969

*Note: lyh denotes per-capita income, lp denotes population, pupc is the percentage of urban population over total population and lia is the percentage of industrial activity over total GDP. t-statistics are in brackets. *, **, *** denote significance at the 10, 5, and 1% level, respectively.*

Table A.6. Generalized least squares estimation results with population weights (various years/ upper-middle-income countries)

	1975	**1980**	**1985**	**1990**	**1995**	**2000**	**2003**
lyh	0.817*	0.628	0.796**	1.410***	0.693*	0.479	0.585*
	(1.79)	(1.66)	(2.33)	(9.28)	(1.82)	(1.5)	(1.82)
lp	1.066***	1.160***	1.176***	1.230***	1.231***	1.231***	1.271***
	(5.04)	(13.69)	(20.45)	(30.95)	(18.46)	(16.19)	(13.76)
pupc	-1.157	-0.393	-1.430***	-1.063**	-0.258	-0.88	-1.760**
	(-0.90)	(-0.74)	(-2.77)	(-2.08)	(-0.39)	(-1.60)	(-2.20)
lia	0.894	1.234**	1.688***	1.387***	2.520***	1.466***	1.289***
	(1.44)	(2.66)	(3.16)	(7.57)	(4.98)	(3.46)	(3.49)
Constant	-15.82***	-17.70***	-20.56***	-25.89***	-24.04***	-18.10***	-18.51***
	(-3.63)	(-12.90)	(-12.97)	(-20.57)	(-4.82)	(-4.55)	(-4.54)
Observations	11	21	26	33	34	34	34
Adjusted $\mathbf{R}^2$	0.842	0.946	0.946	0.978	0.942	0.934	0.926

Note: lyh denotes per capita income, lp denotes population, pupc is the percentage of urban population over total population and lia is the percentage of industrial activity over total GDP. t-statistics are in brackets., **, *** denote significance at the 10, 5, and 1% level, respectively.*

A.7. Lists of countries in each group

Low income

- Bangladesh
- Benin
- Burkina Faso
- Burundi
- Cambodia
- Central African Republic
- **Chad**
- **Comoros**
- Congo, Dem. Rep.
- Cote d'Ivoire
- **Eritrea**
- Ethiopia
- Gambia, The
- Ghana
- **Guinea**
- **Guinea-Bissau**
- Haiti
- India
- Kenya
- Kyrgyz Republic
- **Lao PDR**
- **Madagascar**
- **Malawi**
- **Mali**
- **Mauritania**
- **Mongolia**
- Mozambique
- Nepal
- **Niger**
- Nigeria
- Pakistan
- Papua New Guinea
- **Rwanda**
- **Sao Tome and Principe**
- Senegal
- **Sierra Leone**
- Solomon Islands
- Sudan
- Tajikistan
- Tanzania
- Togo
- **Uganda**
- Uzbekistan
- Vietnam
- Yemen, Rep.
- Zambia

Lower-middle income

- Albania
- Algeria
- Angola
- Armenia
- Azerbaijan
- Belarus
- Bolivia
- Brazil
- Bulgaria
- Cameroon
- **Cape Verde**
- China
- Colombia
- Congo, Rep.
- **Djibouti**
- **Dominican Republic**
- Ecuador
- Egypt, Arab Rep.
- El Salvador
- Fiji
- Georgia
- Guatemala
- **Guyana**
- Honduras
- Indonesia
- Iran, Islamic Rep.
- Jamaica
- Jordan
- Kazakhstan
- **Kiribati**
- **Lesotho**
- Macedonia, FYR
- **Micronesia, Fed. Sts.**
- Moldova
- Morocco
- Namibia
- Nicaragua
- Paraguay
- Peru
- Philippines
- **Samoa**
- Sri Lanka
- **Suriname**
- **Swaziland**
- Syrian Arab Republic
- Thailand
- **Tonga**
- Tunisia
- Ukraine

Upper-middle income

- Argentina
- **Belize**
- Botswana
- Chile
- Costa Rica
- Croatia
- Czech Republic
- Dominica
- **Equatorial Guinea**
- Estonia
- Gabon
- **Grenada**
- Hungary
- Latvia
- Lebanon
- Lithuania
- Malaysia
- **Mauritius**
- Mexico
- Oman
- Panama
- Poland
- Romania
- Russian Federation
- **Seychelles**
- Slovak Republic
- South Africa
- **St. Lucia**
- Turkey
- Uruguay
- Venezuela, RB

Source: World Development Indicators 2007. For countries in **bold** energy efficiency was not available.

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