# The Impact of Population on CO2 Emissions: Evidence From European Countries

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## Summary

This paper analyses the impact of population growth on CO2 emissions in European Union countries. Traditionally, researchers have assumed a unitary elasticity of emissions with respect to population growth. In this study population is treated as a predictor in the model, instead of being included as part of the dependent variable (per capita emissions), thus relaxing the above-mentioned assumption of unitary elasticity. We also contribute to the existing literature by taking into account the presence of heterogeneity in the sample and considering a dynamic specification. The sample covers the period 1975- 1999 for the current European Union members. Our results show that the impact of population growth on emissions is more than proportional for recent accession countries whereas for old EU members, the elasticity is lower than unity and non significant when the properties of the time series and the dynamics are correctly specified. The different impact of population change on CO2 emissions for the current EU members should therefore be taken into account in future discussions of climate change policies within the EU.

**Keywords:** CO2 Emissions, European Union, Panel Data, Population Growth

**JEL Classification:** Q25, Q4, Q54

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## 1. INTRODUCTION

Economic activity promotes wealth creation but has negative effects on the environment. The production systems currently used in industrialized countries generate vast quantities of waste and contamination, causing degradation to natural resources. These impacts are more severe when accompanied by demographic growth, as long as population increases lead to increases in energy consumption and, consequently, to greater atmospheric pollution.

A number of researchers have recently considered demographic factors in order to explain the sources of air pollution. The first studies where 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 relation 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 CO2 emissions and energy use with respect to population are close to unity.

In a panel data context, Shi (2003) found a direct relationship between population changes and carbon dioxide emissions in 93 countries over the period 1975-1996. A similar result was obtained by Cole and Neumayer (2004). These authors considered 86 countries during the period 1975-1998 and they found a positive link between $CO_2$ emissions and a set of explanatory variables including population, urbanization rate,

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[1] Impact-Population-Affluence-Technology.

energy intensity and smaller household sizes. Previous research also outlined the negative environmental impact caused by demographic pressure (Daily and Ehrlich, 1992; Zaba and Clarke, 1994), but they failed to analyse this impact within an appropriate quantitative framework.

In addition to the abovementioned approaches, 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 (see Table A.1 in the Appendix for a relation of $CO_2$-EKC studies). 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 not 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 non-appropriated techniques and the presence of omitted variables bias. 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 (Perman and Stern, 2003). 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 environmental Kuznets curve hypothesis cannot be generally accepted.

A number of studies utilized total energy use as a proxy for total environmental impact. In this line, Cole et al. (1997) and Suri and Chapman (1998) found that energy use per capita increases monotonically with income per capita. However, when energy intensity is considered as the dependent variable, it declines with rising income or even shows a U-shaped curve (Galli, 1998). The relationship between energy use and income is a widely studied topic in the field of energy economics. The empirical findings presented in the last two decades, since the seminal article published in the late seventies by Kraft and Kraft (1978), have been mixed or conflicting. The results depend on the sample of countries, the years under analysis and the estimation techniques used. Some studies found evidence in favour of causality running from GDP to energy consumption (Kraft and Kraft, 1978), for some others no causal relationship was found (Yu and Hwang, 1984; Yu and Choi, 1985 and there are also studies showing that the causality runs in the opposite direction: from energy consumption to GDP (e.g. Lee, 2005). Nevertheless the study of this relationship is beyond the scope of this paper.

Among the recent developments concerning the investigation of the environment-development relationship 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 difference between both approaches is that the first one 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 main two factors increasing carbon emissions in OECD countries, whereas the decrease in energy intensity is the main factor reducing them. Bruvoll and Medin (2003) covered ten pollutants and find out that in all cases technique effects were dominant in offsetting the increase in scale. The authors conclude that whereas structural change explains the increase in energy intensity during 1913-70, 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 1973-1990 and find out that the contribution of input and output effects to changes in global emissions is very modest, whereas technological change considerably reduces the increase in emissions.

The aim of this paper is to analyse the impact of population growth on $CO_2$ emissions in European Union countries, by using an econometric model to decompose emissions into the scale, composition and technique effects described above. We take into account dynamic effects, the time series properties of the data and the presence of heterogeneity in the sample. To our knowledge, this is the first systematic quantitative study of the population-emissions relationship within the EU[2]. We specify a model in which $CO_2$ emissions are related with the level of income per capita and the population size, the industrial structure and the energy intensity of each country. The study involves the current EU Members and analyses separately the behaviour of old and new accession countries. The results show important disparities between the most industrialised countries and the rest.

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[2] Bengochea-Morancho *et al.*, 2001 analysed the relationship between economic growth and $CO_2$ emissions in the European Union in the EKC framework.

We think this subject needs special attention nowadays, since the European Union is willing to fulfil the Kyoto commitment[3] of reducing greenhouse gas emissions by 8% in 2008-2012 with respect the 1990 levels. The main greenhouse gas in terms of quantity is $CO_2$, which, according to UNEP (1999), accounts for about 82% of total anthropogenic greenhouse gas emissions in developed countries.

The EU has included the reduction of emissions among the high-priority objectives of the 6th Environmental Programme. Within the European bubble system not all the Member States would have to curb their emissions to the same extent; moreover, some countries are allowed to increase their emissions in order to favour their real convergence. This raises the question as to what are the relevant factors explaining greenhouse emissions in order to find a suitable policy on emissions quotas allocation. So far, the amounts of $CO_2$ fixed in 1997 for European countries have remained unchanged. Two Directives have been launched in order to implement the flexibility mechanism to achieve the Kyoto targets: the Directive on the greenhouse gas emissions allowance trading scheme and the Directive on project mechanisms[3]. The European Commission has also drawn up guidance on National Allocation Plans (NAPs). According to the NAPs each Member State has to allocate the amount of tradable permits of $CO_2$ emissions among the installations affected by the Directives mentioned above over the period 2005-2007. For the next period 2008-2012 and successive periods each EU member will be required to prepare another NAP. Therefore, it is important to

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[3] Six gases were covered under this agreement: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. The main greenhouse gas in terms of quantity is carbon dioxide (CO2).

[3] The project based mechanisms allow countries to become partners to reduce emissions. Under the clean development mechanism an Annex B country implements clean technologies in a developing country and it obtains certificates of the reduction achieved in emissions. The Joint Implementation Mechanism refers to any two Annex B countries. These mechanisms are of significant interest to both Economies in Transition and developing countries.

analyse the factors that must to be taken into account when establishing national emission quotas, especially with the last enlargement of the EU to 25 countries in 2004 and expected future enlargements, since these new members will also have to achieve some reduction targets. Hence, effective criteria to establish national quotas will require a greater knowledge of the factors influencing the atmospheric pollutants in each European country.

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

## 2. THEORETICAL FRAMEWORK

We may intuitively state that mankind's activities influence the level of $CO_2$ emissions in the atmosphere. However, it is more difficult to determine what specific factors represent mankind's activities and to what extent each of them contributes to the increase or decrease of the $CO_2$ emissions.

Erlich and Holdren (1971) suggested a suitable framework to analyse 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 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 directly used to test hypotheses on the impact of each one of the abovementioned 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 only 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 lead to different predictions in all the regions of the world, always being higher the impact on emissions for the *I=HAT* model, where households replaces 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 to estimate population elasticities. For such estimation they use the model proposed by Dietz and Rosa (1997). Starting from the idea of Ehrlich and Holdren (1971), Dietz and Rosa (1997) formulate a stochastic version of the IPAT equation, with quantitative variables containing population size (*P*), affluence per capita (*A*) and the weight of the 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; $\alpha$, $\beta$, $\gamma$ and $\delta$ 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 more than proportional impact in $CO_2$ 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 analysed 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. 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 the energy intensity. 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 analysed in a single model and under the appropriate quantitative framework.

## 3. EMPIRICAL ANALYSIS

Following the empirical model formulated by Dietz and Rosa (1997), we have estimated a linear version of the STIRPAT model for a sample of 23 European Union countries during the period 1975-1999. The countries under analysis are the 15 Member States since 1995 and eight new countries that joined the EU in May 2004: the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia and Malta. With the exception of Malta, all of them are European Eastern countries in transition from a planned economy to a free market system. The data were taken from the World Development Indicators (World Bank, 2001). Some values are missed in the data for accession countries since most of them only report data since the 1980s, when their economies began the opening up process.

In order to test whether the evolution through time and across countries of the factors considered in the STIRPAT model influence the level of $CO_2$ emissions, we have derived the empirical model by taking logarithms of equation [1],

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

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 PPP 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 intensity (EI). Finally, $\delta_i$ and $\phi_t$ 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 directly be interpreted as elasticities. The time effects, $\phi_t$ can be considered as a proxy for all the variables that are common across countries but vary over time. Within the context of decomposition analysis (Stern, 2002) these effects are sometime interpret as the effects of emissions specific technical progress over years t.

Equation [2] was first estimated for the whole set of countries under analysis (an unbalanced panel with 529 observations). Table 1 shows the results obtained by using different estimation methods.

**Table 1: The determinants of the $CO_2$ emissions (enlarged EU)**

The first column shows the ordinary least squares estimates (OLS), for comparative purposes. The second column present the estimated obtained by adding country and time[4] fixed effects (FE) and the third column presents the generalized least squares estimates with random effects (RE). The null hypothesis of non-significance of the

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[4] In order to save space, time effects are not reported. Available upon request.

individual effects is rejected, according to the Wald test outcomes. Therefore, we cannot accept a common constant term for all the countries (OLS results), since each country starts from a different level of emissions. With respect to the random effects approach, we have applied the Hausman test in order to test for orthogonality between the random effects and the regressors. According to the Hausman test outcomes, only the coefficients of the model specified with fixed effects are consistent in the enlarged EU. The estimated coefficients show the expected positive sign and magnitude and are similar to those found in other comparable studies (Shi, 2003). However, two problems arise from these estimation results. On the one hand, population and GDP per capita are highly correlated (r=0.93), generating collinearity. On the other hand the series may be non-stationary. A matter of great concern is the danger of spurious regressions when the data are non-stationary. We test for the non-stationarity of the variables in our model with two different test: the Levin, Lin and Chu (2002) and the Im, Pesaran and Shin (2003) unit root tests for panel data. The former test assumes a common AR structure for all the series, whereas the latter allow for different AR coefficients in each series. Results are presented in Table A2 in the Appendix. Both tests indicate that for almost all the series in levels we reject the null hypothesis of non-stationarity. Only for $CO_2$ and energy intensity in levels we could not reject the null. This is not the expected outcome since we know that GDP series and population have normally a unit root according to the research undertaken in the time series literature. This may be due to the fact that the number of periods is not high enough to consistently apply this methodology. Nevertheless, all the variables were stationary in first differences. Therefore, we took first differences of all the variables and re-estimated Model 1. Results are presented in column 4 of Table 1. We can observe that the emissions-population elasticity present a lower coefficient than before for the extended sample.

Estimating the model in first differences also solves the problem of collinearity since the first-differenced series present a much lower correlation coefficient.

Finally, we estimated a dynamic panel data model in order to consider the possibility that actual emissions depend on pass emission levels and giving more flexibility to the estimation procedure. We apply the Generalised Method of Moments (GMM) method to the transformed series (first differences) and we used as valid instruments all the exogenous variables and the second lag of the dependent variable. Results are shown in the last column of Table 1.

The results obtained by estimating the model in first differences show that population growth presents a non significant estimated coefficient and the same occurs when dynamics are taken into account in column five. The preferred model is the dynamic specification estimated with the generalised method of moments' technique and the series in first differences and using as instruments all the exogenous variables in the model and the second lag of the endogenous variable. The column of GMM results shows that the emissions-population elasticity is lower than unity (0.55) and the estimated coefficient is non significant. The effect of a 1% increase in GDP per capita is an increment in $CO_2$ of 0.42%, the contribution of the weight of the industry in the economy is 0.23% and the contribution of energy intensity is 0.44%.

In order to check for the validity of the results we performed a set of test. First we introduced in the model a set of interaction dummies to separate the sample into two sub-samples (old EU members and new EU members) and to test for heterogeneity in the slope coefficients of the four explanatory variables. Since the interaction dummies were all statistically significant, we could not accept that any of the four coefficients were equal for both groups of countries. We opt by estimating two separate models for old and new accession countries because in this way we can choose the most appropriate estimation method for each sub-sample. Results are shown in Tables 2 and 3, and in fact, the results indicate that for old EU members a dynamic model is the best specification, whereas for new accession countries a static model is preferred.

**Table 2: Determinants of $CO_2$ emissions (old EU members)**

In the estimation results for old EU countries (Table 2) the estimated coefficients also show the expected signs, although there are changes in the magnitude and significance of the estimated coefficients. The population coefficient is now significant at 10% level in the dynamic specification (last column of Table 2) and shows a magnitude of 0.77. The results show an increase in the contribution of the population and the share of industrial activity and a decrease in the contribution of the income per capita and the energy intensity variables to the $CO_2$ loads with respect to the results for the enlarged EU.

**Table 3: Determinants of $CO_2$ emissions (EU recent accession countries)**

The group of countries that joined the EU in 2004, (Table 3) show very different results. A static model is the most appropriate specification. The signs of the coefficients are as expected and the explanatory variables are significant. The greater impact that population has on $CO_2$ emissions in these countries with respect to old accession ones should be noted: a 1% increase in population leads to a 2.73% increase in carbon dioxide emissions. Income per capita shows a higher coefficient in comparison to old accession countries and the share of industry in GDP loses significance and decreases in magnitude. For energy intensity the coefficient remains unchanged.

Table 4 presents the time effects of both groups of countries, old and new EU members. In both cases we observe an overall decreasing trend in the magnitude of the time effects, but since the middle 80s this trend is more pronounced for the recent accession countries. 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 recent accession countries and in the latest years of the sample.

**Table 4: Time effects, old and new accession countries**

We test for the presence of heteroskedasticity, in a panel data context, with a variant of the White test. We run an auxiliary regression where the dependent variable is the square residuals and the independent variables are all first moments, second moments and cross products of the original regressors. The resulting test statistic $N(T-1)R^2$ of this regression follows a $\chi^2$ with k-1 degrees of freedom. Since the null hypothesis of homoskedasticity is rejected, the estimations are run with heteroskedaticity-consistent standard errors.

We also test for first order autocorrelation in the data, by estimating the slope, $\hat{\rho}$ in the artificial regression,

$$\varepsilon_{it} = \rho\varepsilon_{it-1} + \upsilon_{it} \qquad [3]$$

If there is autocorrelation, then the slope of this regression will be an estimator of $\rho = corr[\varepsilon_{it}, \varepsilon_{it-1}]$. We test for the null hypothesis that ρ equals zero. Treating [3] as a classical lineal model and using a *t* test to test the hypothesis is a valid way to proceed based on the Lagrange multiplier principle. Since the fixed effects estimates are consistently estimated, for simplicity we test for autocorrelation in the fixed effects model. We did not find autocorrelation in the residuals.

## 4. DISCUSSION

The results obtained for old EU members (Table 2) show a lower contribution of some the explanatory variables (population and affluence) to explain the variability of the $CO_2$ loads with respect to the results for last accession countries (Tables 3 and 4). This is in accordance with the EU emissions situation in recent years, especially regarding the most polluting countries such as the United Kingdom and Germany, where moderate economic growth has coincided with a slight population increase and a progressive decrease of the industrial sector.

The main differences between the two sets of results concern population. The elasticity emissions-population is much lower for old EU members when the model is estimated in first differences for the two sub-samples and dynamics are taken into account, whereas for recent accession countries it is much higher than unity (2.73) and significant. A great number of studies confirm an overall upward trend in global emissions along 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, we find that for developed countries (old EU members) the emissions-population elasticity presents a lower coefficient. Shi (2003) calculated an elasticity of 1.58 for 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. However, Cole and Neumayer (2004) reported a unitary elasticity for $CO_2$. Their result might be due to the presence of heterogeneity in their sample since they include developed and developing countries in a single set, leading to compensation in their contributions, as in our first estimation reported in Table 1 (column 4).

Nowadays, population is falling in most European accession countries and it is not clear whether the results will hold for population decline in a symmetric way. According to the study carried out by MacKellar et al. (1995), it is unlikely to expect the $CO_2$ emissions to curb since there is an increase in the number of households simultaneously to a households size decrease. In East Europe the average household size was 3.7 in 1950, 3.3 in 1970 and 2.9 in 1990. In West Europe this figures were 3.5, 3.1 and 2.6. Since emissions also depend on residential energy consumption, automobile transport and other facts attached to the urbanization processes, the implications from the regression results for a declining population are uncertain.

Some differences have also been observed in the other explanatory variables. An increase of 1% in the GDP per head causes only a 0.15% increase in $CO_2$ emissions of old EU members and a 0.34% (twofold) in recent accession countries. The contribution of the industrial sector to emissions is also different: in the first group the impact of the industrial sector on emissions is higher than that obtained for the new EU members (the elasticities are 0.42 and 0.24 respectively). To sum up, the environmental impact cause by population and affluence variables (scale effect) seems to be higher in last accession countries, whereas the declining of energy intensity has a similar role to play in reducing $CO_2$ emissions for all EU current members.

## 5. CONCLUSIONS

We have conducted a multivariate analysis on the determinants of carbon dioxide emissions in the European Union during the period 1975-1999. The usual assumption of unitary elasticity in the emission-population relationship has been relaxed. With this aim, we 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. We have applied panel data econometrics and used several estimation methods.

The results show different patterns for old and new EU members. For the first set of countries, the elasticity emission-population is lower than unity, whereas in the second group the elasticity is 2.73, which is in accordance with the higher environmental impact observed in less developed regions. Nevertheless, it remains unclear whether a demographic decline will curb $CO_2$ emissions. Some differences were also shown in other factors, the scale effect always show a higher impact on $CO_2$ emissions in the regressions concerning new EU members.

These results indicate that a review of the Communitarian emissions policy, that takes into account the characteristics of the new EU members, would be desirable. The European Commission has approved two Directives establishing a scheme for greenhouse gas emission allowance trading and for the project based mechanisms. Several factors must be taken into account when establishing the allocation of emission quotas to each country, including population dynamics, incomes and productive structures and energy intensities, since according to our study, all these variables significantly influence the volume of $CO_2$ emissions.

Nevertheless, we must be cautious about the conclusions drawn, due to the lack of homogeneity in statistical data for the whole sample of countries. In this sense, further research with more data and alternative exogenous variables would contribute to improve the knowledge of the phenomenon under study.

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## Table 1: The determinants of the $CO_2$ emissions (enlarged EU)

| Variable | OLS | FE | RE | First dif. | GMM (DPD) |
|---|---|---|---|---|---|
| Constant | -4.29 (-5.16) | - | -3.02 (-2.50) | - | - |
| lnP | 1.85 (11.50) | 1.78 (2.22) | 1.37 (15.34) | 1.12 (1.52) | 0.55 (0.88) |
| lnA | 0.89 (5.47) | 1.12 (6.29) | 0.35 (15.69) | 0.88 (6.26) | 0.42 (4.87) |
| lnT | 0.26 (0.70) | 0.54 (2.04) | 0.89 (10.75) | 0.27 (2.45) | 0.23 (1.81) |
| LnEI | 0.76 (4.12) | 0.95 (8.05) | 0.72 (12.826) | 0.72 (9.86) | 0.44 (5.20) |
| LnCO2(-1) | - | - | - | - | 0.59 (13.01) |
| Period Effects | Yes | Yes | - | Yes | Yes |
| $R^2$ | 0.96 | 0.99 | 0.92 | 0.36 | |
| S.E. of the regression | 0.28 | 0.12 | 0.14 | 0.07 | 0.09 |
| FE significance | | 86.29 | | | |
| Wald test | | $\chi^2(23)=798.45$ | | | |
| Hausman test | | | $\chi^2(4)=35.33$ | | |
| $N(T-1)R^2$(Auxiliary regression) | | 16.7** | | | |
| $\hat{\rho}$ $(\varepsilon_{it} = \rho\varepsilon_{it-1} + \upsilon_{it})$ | | 0.18 (1.45) | | | |

Notes: Ln denotes natural logs, P denotes population, A denotes gross domestic product per capita, T denotes the percentage of industrial activity in total GDP and EI denotes energy intensity. Heteroskedasticity-consistent t-values are shown in brackets. Country specific effect are not reported in column three (Fixed Effects) and four (Random Effects).

## Table 2: Determinants of $CO_2$ emissions (old EU members)

| Variable | OLS | FE | RE | First dif. | GMM(DPD) |
|---|---|---|---|---|---|
| Constant | -5.34 (-14.9) | - | 2.57 (1.83) | - | - |
| lnP | 1.82 (80.47) | 2.24 (16.14) | 1.27 (25.00) | 1.58 (0.35) | 0.71 (1.79) |
| lnA | 0.95 (38.57) | 1.30 (19.98) | 0.36 (13.23) | 1.25 (5.93) | 0.15 (3.04) |
| lnT | 0.36 (4.23) | 0.62 (3.59) | 0.99 (9.37) | 0.37 (2.53) | 0.42 (5.37) |
| Ln EI | 0.43 (8.76) | 1.09 (25.29) | 0.80 (11.33) | 1.07 (8.65) | 0.36 (6.16) |
| LnCO2(-1) | | | | | 0.68 (18.28) |
| Period Effects | Yes | Yes | - | Yes | Yes |
| $R^2$ | 0.95 | 0.98 | 0.98 | 0.35 | |
| S.E. of the regression | 0.25 | 0.12 | 0.14 | 0.07 | 0.10 |
| FE significance | | 703.81 | | | |
| Wald test | | $\chi^2(15)=103.25$ | | | |
| Hausman test | | | $\chi^2(3)=10.08$ | | |
| $N(T-1)R^2$ | | 14.2** | | | |
| $\hat{\rho}\ (\varepsilon_{it} = \rho\varepsilon_{it-1} + \upsilon_{it})$ | | 0.67 (1.02) | | | |

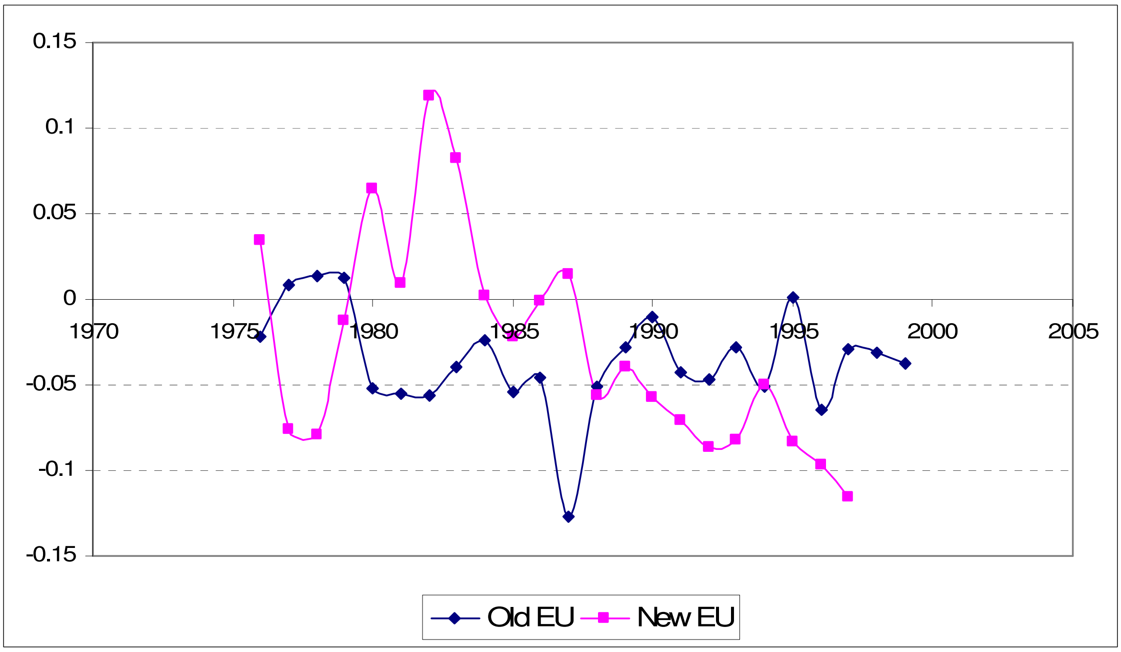
Notes: Ln denotes natural logs, P denotes population, A denotes gross domestic product per capita, T denotes the percentage of industrial activity in total GDP and EI denotes energy intensity. Heteroskedasticity-consistent t-values are shown in brackets. Country specific effect are not reported in column three (Fixed Effects) and four (Random Effects).

## Table 3: Determinants of $CO_2$ emissions (EU recent accession countries)

| Variable | OLS | FE | RE | First dif. | GMM(DPD) |
|---|---|---|---|---|---|
| Constant | -5.38 (-4.16) | - | -7.03 (-1.72) | - | - |
| lnP | 2.15 (16.61) | 2.52 (3.49) | 1.62 (16.86) | 2.73 (2.98) | 5.11 (1.60) |
| lnA | 1.11 (9.46) | 0.90 (5.78) | 0.44 (14.76) | 0.34 (2.60) | 0.51 (1.73) |
| lnT | -0.32(-1.30) | 0.37 (2.97) | 0.80 (9.03) | 0.24 (1.76) | 0.42 (3.35) |
| Ln EI | 1.46 (14.12) | 0.61 (3.87) | 0.51 (7.33) | 0.38 (4.53) | 0.12 (0.42) |
| LnCO2(-1) | | | | | -0.61 (-1.18) |
| Period Effects | Yes | Yes | - | Yes | Yes |
| $R^2$ | 0.99 | 0.99 | 0.93 | 0.68 | 0.58 |
| S.E. of the regression | 0.21 | 0.05 | 0.08 | 0.05 | 0.06 |
| FE Significance | | 298.59 | | | |
| Wald test | | $\chi^2(8)=132.2$ | | | |
| Hausman test | | | $\chi^2(3)=25.23$ | | |
| $N(T-1)R^2$ | | 23.4** | | | |
| $\hat{\rho}\ (\varepsilon_{it} = \rho\varepsilon_{it-1} + \upsilon_{it})$ | | 0.43 (1.42) | | | |

Notes: Ln denotes natural logs, P denotes population, A denotes gross domestic product per capita,T denotes the percentage of industrial activity in total GDP and EI denotes energy intensity. Heteroskedasticity-consistent t-values are shown in brackets. Country specific effect are not reported in column three (Fixed Effects) and four (Random Effects).

## Table 4: Time effects for old and new accession countries



Notes: New accession countries considered: CZ: Czech Republic; ES: Estonia; HU: Hungary; LA: Latvia; LI: Lithuania; POL: Poland; SL: Slovakia; MA: Malta.

# Appendix

*Table A.1. $CO_2$ EKC studies in chronological order*

| Autors | Turning Points | PPP | Additional Variables | Data source for $CO_2$ | Time period | Estimation technique | Functional form | EKC | Countries |
|---|---|---|---|---|---|---|---|---|---|
| Shafik and Bandyopadhyay (1992) | $7Million | Yes | Yes (Market premium, dollar index) | Marland (1989) | 1961-86 | Fixed Effects, Random Effects | Linear, Quadratic and Cubic (logs) | No | 118-153 |
| Holtz-Eakin and Selden (1995) | $35428(level)-$8 Mill. (logs) | Yes ($1986) | No | ORNL[b] | 1951-86 | Two ways Fixed Effects | Quadratic (levels and logs) | Yes | 108 |
| Tucker (1995) | Decreasing over time | | No | WRI (1994) | 1971-91 | Yearly Cross-sectional analysis. First Differ. | Quadratic | In 11 years | 137 |
| Sengupta (1996) | $8740 | Yes ($1985) | No | ORNL[b] | | Fixed Effects | Quadratic | Yes | 16 Developed + Developing |
| Cole, Rayner and Bates (1997) | $25100(levels)-$62700 (logs) | No | Yes (Trade, pop.d., tech) | Marland et al. (1994) | 1960-92 | Generalized Least Squares | Linear, Quadratic (levels and logs) | Yes | 7 World Regions |
| Moomaw and Unruh (1997) | $12813 | ($1985) | No | World Bank (1992) | 1950-92 | Fixed Effects | Structural Transition Model, Cubic form | N shaped | 16 Developed |
| Roberts and Grimes (1997) | $8000-$10000 | Yes | No | ORNL[b] | 1962-91 | Cross-section analysis | Quadratic | Yes, after the 70s | Developed + Developing |
| Schmalensee, Stoker and Judson (1998) | Within sample | Yes ($1985) | No | ORNL[b] | 1950-1990 | Two ways Fixed Effects | Spline Function | Yes | 141 |
| Agras and Chapman (1999) | $13630 | Yes | Yes (Price, trade var.) | IEA[a] and ORNL[b] | 1971-89 | Autorregressive-Distributed Lag with Fixed Effects | Quadratic (logs) | No | 34 |
| Galeotti and Lanza (1999) | $15073-$21757 | Yes ($1990) | No | IEA[a] | 1971-96 | Least Squares Dummy Variable | Non linear Gamma and Weibull | Yes | 110 |
| Panayotou, Peterson and Sachs (2000) | $29732-$40906 (1950-1990) | Yes | Yes (Trade, K, pop. d.) | CDIAC[c] (1997) | 1870-1994 | Feasible Generalized Least Squares | Quadratic | Yes for Developed | 17 Developed |
| Heerink et al. (2001) | $68871 | Yes | Yes (Inequality) | Marland (1989) | 1985 | Generalised Method of Moments | Quadratic (logs) | Yes | 118-153 |
| Roca et al. (2001) | $Y^2$ non sign. | No ($1986) | Yes (Energy prices) | IEA[a] | 1973-96 | Time series, cointegration | Linear, Squared and Cubic (logs) | No | Spain |
| Baiocchi and di Falco (2001) | $Y^2$ non sign. | Yes | No | World Resources Institute | | Nonparametric method | Local polynomial | No | 160 |
| Bengochea et al. (2001) | $24427-$73170 | Yes | No | OECD Environmental Data | 1980-95 | Fixed Effects, Random Effects, Instrumental Variables, First Differ. | Linear, quadratic, cubic | For some countries | UE |
| Dijkgraaf and Vollebergh (2001) | $20647 | No ($1990) | No | OECD 2000<br>IEA (1991)[a] | 1960-97 | Fixed Effects, Seemly Unrelated Regression | Linear, quadratic, cubic. Slope heterogeneity | Yes 5 rich countries | 24-OECD |
| Martínez-Zarzoso and Bengochea-Morancho (2004) | $4914-$18364 | Yes ($1993) | No | World Development Indicators 2001 | 1975-98 | Pooled Mean Group | Linear, quadratic, cubic. Slope heterogeneity | N shaped | 22-OECD |

Notes: a: International Energy Agency: Greenhouse Gas Emissions: The Energy Dimension (Paris, OECD, 1991), b: Oak Ridge National Laboratory, c: Carbon Dioxide Information Analysis Centre, e: World Resources Institute.

Table A.2. Pool Unit Root tests results

| **Method** | **lnco2** | **Δlnco2** | **lnpop** | **Δlnpop** | **lngdp** | **Δlngdp** | **lnind** | **Δlnind** | **lnEI** | **ΔlnEI** |
|---|---|---|---|---|---|---|---|---|---|---|
| Null: Unit root (assumes common unit root process) | | | | | | | | | | |
| Levin, Lin & Chu t* | -1.68 | -20.08** | -5.76** | -2.80** | -5.25** | -2.54** | -3.64** | -15.81** | 0.67 | -16.39** |
| Null: Unit root (assumes individual unit root process) | | | | | | | | | | |
| Im, Pesaran and Shin W-stat | -1.02 | -7.67** | -2.62** | -3.01** | -2.51** | -4.10** | -3.29 | -9.92** | 2.93 | -16.84** |
| Nobs | 465 | 444 | 546 | 519 | 438 | 411 | 485 | 461 | 465 | 444 |

Note: Exogenous variables: Individual effects, individual linear trends. Automatic selection of lags based on SIC: 0 to 2maximum lags. Newey-West bandwidth selection using Bartlett kernel.

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